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JULIUS SCHEINER

THE

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JULIUS SCHEINER

By EDWIN B. FROST

After a long and painful illness, which had greatly restricted his scientific activity for many months, Julius Scheiner, a senior observer at the Royal Astrophysical Observatory at Potsdam, and extraordinary professor of astrophysics at the University of Berlin, died on December 20, 1913, at Potsdam. He was born at Cologne on November 25, 1858, the son of Jacob Scheiner, a painter of landscapes and architectural subjects of that city.

Julius Scheiner attended the elementary schools at Deutz, a suburb of Cologne, later entering the Realgymnasium in the city. His interest was early aroused in physics, partly by the genius of his teachers in that branch, to whom he acted as an assistant. Upon passing his *Abiturienten* examination in the spring of 1878, he entered the University of Bonn, devoting his attention chiefly to mathematics and natural science. He had as a schoolboy visited the famous observatory at Bonn, and the interest then developed soon led him to turn his attention to astronomy as a career. The traditions of the institution established by Argelander and then directed by Schönfeld doubtless had their full influence upon the young student. He was skilful in the use of instruments and after a couple of years at the

university took part in the observations of the observatory. He took his Doctor's degree in the spring of 1882, with a thesis which discussed the observations of Algol made by Schönfeld at Mannheim from 1869 to 1875. He had already received the appointment as assistant at the observatory and was assigned to the zone observations with which Dr. Deichmüller was engaged.

At this period came the year of military service, which, contrary to expectation, proved to be of benefit to the health of the young man, who already had some heart trouble. He thereafter returned to his work and made himself valuable as well as personally attractive to Schönfeld and an interesting circle of scientific men at Bonn. The emoluments of his position at the observatory were not such, however, that he could forsee the realization of his hopes of marriage (having been engaged for some years), and he looked for an opportunity for work in the recently established astrophysical observatory at Potsdam under the efficient direction of H. C. Vogel. It was not for a couple of years that a position could be offered him that promised a living and gave hope of future advancement, but, on January 1, 1887, the young Rheinländer entered the service of the astrophysical observatory where for a quarter of a century he was destined to find a full opportunity for the exercise of his marked talents as an investigator and writer. Vogel had been a student in Leipzig of Zöllner, the first German professor of astrophysics, and thus Scheiner's intellectual pedigree in astrophysics runs back to as appropriate a source as it had in Bonn for the older branch of astronomy.

The work in progress at Potsdam was at a very interesting phase: the work on the astrographic chart was just beginning, and many new problems, both instrumental and theoretical, had to be worked out. Vogel was also planning to apply the photographic process to the measurement of stellar velocities in the line of sight, his earlier work by the visual method having convinced him of the prohibitive difficulties of that mode of observation. As the health of Vogel did not permit him to take much part in the actual observations with the new instrument which he had designed and named the spectrograph, Scheiner had an unusual opportunity to collaborate with his chief, and his zeal and skill contributed much to the suc-

cessful outcome of the experiments of the new method. In 1888 and 1889 observations were secured of the 50 brighter stars with the spectrograph attached to the Schroeder refractor of 12 in. (300 mm) aperture. The plates were measured by both Vogel and Scheiner, and the final results were published in Part I of the seventh volume of the *Potsdam Publications* in 1892. Aside from their value for determinations of velocity the spectrograms contained a wealth of information as to their classification, the identification and character of the lines, and their intensities, and precise wave-lengths. This part of the work was assigned to Scheiner by Vogel and appears as the second part of the same volume.

At this time also there was much interest in the observations of the motion in the line of sight of Algol. In the winter of 1888–1889 it was apparent that before a minimum the bright star was moving away from the sun, and toward the sun after a minimum; and plates taken in the following season fully confirmed this, so that a preliminary communication could be made by Vogel and Scheiner to the Berlin Academy on November 28, 1889, of the orbit of the star with an indication of the size and mass of the components.

Scheiner's relations to Vogel became very confidential at this period, and his position corresponded somewhat to that of "assistant to the president" in some of our business corporations. Since Vogel's health could not well undergo the strain of the international conferences, Scheiner was deputed to represent the observatory at the meetings of the delegates of the Astrographic Chart in Paris in 1891, 1896, and 1900. He also attended the meeting in 1909. He also relieved the director of much of the labor of preparing annual reports and generally attended to the numerous scientific visitors who came to Potsdam to learn the methods being introduced in the active institution which was the unquestioned leader in astrophysical work.

Scheiner fully appreciated the eminent services and abilty of Vogel in astrophysics, and Scheiner's work and writings reflected in a marked degree the views of his chief. Scheiner inherited from his father skill in drawing, and shortly after his arrival at Potsdam prepared a valuable set of colored charts exhibiting

Vogel's classification of stellar spectra, and spectra of planets, comets, and nebulae, which were published by a Vienna firm.

Meanwhile Scheiner was also occupied with a work on celestial spectroscopy which the firm of Engelmann of Leipzig (of which one member had been an astronomer) had long desired Vogel to undertake, but which he felt it necessary to decline. The book was *Die Spectralanalyse der Gestirne*, published in the latter part of 1890, with the indorsement of a preface by Vogel, whose views it fully represented. It was received with marked approval by those already interested in celestial spectroscopy and attracted the attention of many others to this branch of astrophysics. It brought to Scheiner considerable reputation as an authority in this field of science. A revised edition in English appeared about four years later and had a considerable sale.

As has been stated, Scheiner was also much occupied in the early nineties with celestial photography and preparations for the astrographic chart. Among the problems was that of reproducing the *reseaux* to be imprinted on the negatives. A method of doing this was worked out by Scheiner and then employed by the French and German instrument-makers. The question of permanency of the sensitive film and of the effect of length of exposure upon the accuracy of the positions were also studied. He investigated the law of the increase of the size of the image with increasing exposure; he also devised a sector sensitometer for testing the speed of plates. He tested the validity of the supposed law of photographic photometry, it=constant, upon which the conference of the Carte du Ciel had based some of its resolutions in 1889, and showed that it was incorrect,[1] and that a two-and-a-half fold increase of exposure caused a gain of nearer half a magnitude than a whole magnitude. He also proposed a simple photographic method for correcting the errors of adjustment of equatorial telescopes.

It should be mentioned that Scheiner was one of the first clearly to recognize what we now call the color-index of a star. In *Astronomische Nachrichten* (**124**, 273, 1890) he published the results of an investigation, "Ueber die Bestimmung von Sterngrössen aus photographischen Aufnahmen," in which he says: "As a result of

[1] He seemed to be unaware that Pickering had previously proved the same thing.

the comparison we may conclude that the differences between photographic and visual magnitudes lie between 1.5 and 2.0 magnitudes for the second spectral type, and certainly exceed 2.5 magnitudes for spectral class IIIa."

The Potsdam photographic refractor having the optical dimensions of the astrographic standard, but with important modifications of the mounting by Repsold to meet the requirements of Vogel, had been set up in 1889, and Dr. Scheiner was occupied with numerous experimental exposures with it. One of the results of this was the measurement (1891) of two negatives of the great cluster in Hercules, Messier 13, from which the positions of 823 stars were determined and the relative magnitudes inferred. The operations are familiar enough nowadays, but it was a new field at that time, and many points had to be worked out from the beginning. It was the writer's great privilege to be associated with Dr. Scheiner in some of this work in 1891 and 1892, and thus to learn to admire the insight and skill of Scheiner at the telescope, in the dark room, and at the measuring machine. In 1894 Scheiner undertook a triangulation of the principal stars (374 in number) and definable points in the Orion nebula, 128 in all, on several photographs taken with the astrographic refractor and with a Voigtländer euryscope. This should serve as a basis for future studies of motions of the nebula and the stars near it. When the routine work of the astrographic chart was begun the duty of its immediate supervision fell to Scheiner, and six large volumes have appeared under his care (I, 1899; VI, 1912), containing the rectangular co-ordinates and approximate places for 1900 of 123,712 stars of the zone from $+31°$ to $+40°$ of declination. The measures of revision and checks were made by Scheiner in many cases, and the scheme of measurement and reduction, described at length in the introduction to the first volume, of course devolved upon him.

The success of *Die Spectralanalyse der Gestirne* led him to undertake the companion volume, *Die Photographie der Gestirne*, which appeared in 1897. It was accompanied by a handsome atlas in heliogravure intended to represent the achievements of celestial photography up to that date. The author's aim, as stated in the preface, was to contribute all in his power to develop celestial

photography into a rigorous and exact science. G. Müller's admirable *Photometrie der Gestirne* completed the series of three works on astrophysics, but in 1899 Scheiner contributed through the same publisher, in a volume of a hundred pages, a monograph entitled *Strahlung und Temperatur der Sonne.* In 1902 Scheiner made observations on the solar constant and temperature of the sun with an Ångström pyrheliometer at the Gorner Grat in Switzerland and at Potsdam, the results of which were published in the eighteenth volume of the *Potsdam Publications.*

After the successful introduction of the spectrographic method of measuring radial velocity of the stars, it was most natural that Vogel should wish to continue that work with a large refractor. His efforts at length obtained the support of the Prussian government, and Scheiner and his colleague Wilsing were occupied in aiding the director in the plans for the new instrument. It was inaugurated with elaborate ceremonies, in the presence of Emperor William, in 1899, and to Scheiner was assigned the part of explaining to the audience some of the details of the great refractor (of 80 cm aperture, with a visual guiding telescope of 50 cm aperture) and of the dome. The high expectations for this splendid instrument, by far the largest in the empire, most unfortunately were not realized, owing to its optical imperfections.[1] The detection of the causes of these defects caused much labor and worry to the director and to the observers assigned to the tests, Messrs. Scheiner, Wilsing, and Hartmann. Unfortunate differences of opinion arose which impaired the close relations between Scheiner and his director, and thereafter executive duties were not often assigned to him. His work with the great telescope was henceforth done in collaboration with his colleague Professor J. Wilsing, with whom his relations were always close.[2] The first investigation, made at the suggestion of Vogel, was a photometric determination of the relative intensities of the three principal lines in the nebular

[1] Successive refiguring has much improved the 80 cm lens, and at this writing we understand that a final retouching has been completed which we may hope will bring it to a satisfactory degree of excellence.

[2] The writer is indebted to Professor Wilsing for a manuscript sketch of the life of his friend Scheiner, upon which much of the present sketch is based.

spectrum. The radial velocities of nine of the brighter gaseous nebulae were next measured visually, the dispersion being supplied by a grating. The results were in good accordance with those made by Keeler visually with the Lick refractor and with some other photographic determinations.

The next important piece of work, and one involving much observational skill, was also done in collaboration with Professor Wilsing and occupies 221 pages of the nineteenth volume of the *Potsdam Publications*, under the title "Temperaturbestimmung von 109 helleren Sternen aus spektralphotometrischen Beobachtungen," 1909. Little or no work had been done in this direction visually since observations were made by Vogel and Müller on a few of the brightest stars about thirty years before. Meanwhile much experimental and theoretical research had been devoted to the black body and the laws of radiation, so that indications could be given of the effective temperature of over 100 stars, many of them as faint as the fourth visual magnitude. To the writer it would seem that the full significance of this important research had not yet been properly appreciated by astronomers, still less by writers of textbooks. It is of the greatest importance to establish that the relation of spectral type and temperature follows the sequence of Vogel's classification, as shown in this extract:

Type	No. of Stars	Temperature ($c = 14{,}200$)
Ib	8	11,500°
Ia1	4	11,600
Ia2	22	10,300
Ia3–IIa	16	7,100
IIa	7	5,900
IIa–IIIa	41	4,200
IIIb	7	3,300

Even if the values of the absolute temperature may be subject to a considerable uncertainty, the determination of the relative value is of the highest importance in any theory of stellar evolution. These results of Wilsing and Scheiner (the former did the work of deriving the temperature from their joint observations) have been

confirmed, relatively, by other investigators, whose determinations would seem, however, to be of far less reliability.

The twentieth volume of *Potsdam Publications* (1909) contains another spectral-photometric research by Wilsing and Scheiner, made in part with the large refractor, entitled "Vergleichende spektralphotometrische Beobachtungen am Monde und an Gesteinen nebst Albedobestimmungen an Letzteren."

In the same volume Scheiner published a catalogue of 1564 double stars found in the first four volumes of the *Potsdam Astrographic Catalogue*, with a statistical study of their relative frequency.

In spite of continuous occupation with research Scheiner still found time for more popular writing and for lectures as extraordinarius at Berlin, where his appointment dated from 1894. In 1908 Teubner published Scheiner's *Populäre Astrophysik*, a fully illustrated work of 718 pages, expanded from his Berlin courses on celestial spectroscopy, photometry, and photography. A second edition appeared in 1912. The style is direct, clear, and holds the reader's attention. In a marked degree Scheiner possessed the art of popularizing, and writing seemed very easy to him.

In 1909 appeared in Barth's series known as "Wissen und Konen" a small volume of 187 pages by Scheiner, entitled *Spektralanalytische und photometrische Theorien*. While not popular (it is printed in the Latin instead of the German type, which is the most obvious distinction in Germany between a scientific and a popular presentation of truth), this work was intended for those interested in astrophysics but not specialists in that branch. It serves a useful purpose.

Scheiner wrote frequently for the semipopular magazines and journals, and he contributed to Teubner's series "Aus Natur und Geisteswelt" a small volume entitled *Der Bau des Weltalls* (1900), of which the fourth edition appeared in 1913. He gave public lectures occasionally, once going by invitation to Lyons for the purpose. His achievements were rewarded by certain of the orders or decorations which are highly regarded by the subjects of monarchical forms of government. He was elected an associate of the Royal Astronomical Society in 1901.

Aside from his capacity as a teacher, Scheiner's most marked ability was on the experimental side of research. He was ingenious with apparatus and could quickly devise an experiment for settling a debated point. After it was settled to his own satisfaction, sometimes perhaps on inadequate data, he was persistent in upholding his view, and this led him into occasional controversies, in which he was sometimes in the wrong. But his faculty of interpretation of nature by experiment must be recognized as unusual; the writer would characterize it as insight.

Scheiner was a jovial companion, a capital story-teller, and enjoyed social gatherings with his colleagues and friends. His home life represented the typical German *Familienglück*. He was married in 1888, and in the first years lived in a modest way in one of the observatory houses on the Telegraphenberg. His wife devoted herself to the interests of her husband and their three daughters and during the illness of his last years he thus received the most constant and affectionate attention. He had always been subject to a nervous affection of the heart and as he had early grown too stout for his best health, it became somewhat difficult for him to take the exercise that was good for him. His eyesight was affected a few years ago so that work at the telescope had to be given up. It was a great satisfaction to the writer to find him in the spring in 1913 in better health than he had been for some time past, so that memories of earlier days could be pleasantly recalled. The apparent improvement continued after his annual visit to the Baltic seashore, and he essayed to resume his work at the observatory in the autumn, but a stroke of apoplexy suddenly ended his life at the far too early age of fifty-five years.

COMPARISON BETWEEN THE DISTRIBUTION OF ENERGY IN THE SPECTRUM OF THE INTEGRATED LIGHT OF THE GLOBULAR CLUSTER MESSIER 3 AND OF NEIGHBORING STARS

By E. HERTZSPRUNG

A spectrum of the integrated light of Messier 3=N.G.C. 5272 ($13^h37^m.5$, $+28°23'$; 1900) was obtained with the UV Zeiss triplet of the Potsdam observatory ($a=15$, $f=150$ cm) in connection with an objective prism of 7°.5 deviation, giving a dispersion of 1 mm to 137 A at H_γ. The exposure on the region of Messier 3 was made February 2, 1914, from $12^h.0$ to $14^h.3$ sidereal time Potsdam, on a Hauff Ultra-rapid plate, under good atmospheric conditions.

The dispersion used is not sufficient to show any lines in the integrated spectrum of the globular cluster. To fix the wave-lengths, therefore, an additional plate was taken without the prism, in order to determine the position of the cluster relative to the stars. It was found in this way that the lines in the spectrum of the star B.D.+28°2251 must be shifted 4.55 mm to the north to coincide with the invisible lines in the spectrum of the cluster.

The spectra of the stars were made 0.29 mm broad by changing the run of the clock and turning back with the slow motion every few minutes. The plate was measured in the Hartmann microphotometer. The small field screened out on the plate by the Lummer-Brodhun prism was of circular shape with a diameter of 0.14 mm. Instead of several settings being made at some few selected wave-lengths, the spectrum was measured throughout in steps of 0.1 mm.

To eliminate the difference between the continuous spectrum of the cluster and the spectra of the stars with sharp absorption lines, the measures of the latter were smoothed graphically to such an extent as to give the spectrum of a cluster consisting only of identical stars. The shape and size of the globular cluster

Messier 3 is roughly equivalent to a uniform circular disk of 40″ or 0.3 mm in diameter.

It was necessary to reduce the scale-readings of the microphotometer to the magnitude scale. This purpose was served by a plate of the north polar region taken on the same night from $9^{h}.4$ to $10^{h}.7$ sidereal time through the objective grating and 3 mm intrafocal, as described in *A.N.*, 4452. A Hauff plate from the same box as for the cluster spectrum was used. The two plates, of the cluster and of the north polar region, were developed together in the same tank and the fog after development therefore proved to be the same in both. On the north polar plate both the central image and the spectra of first order—being different by 0.95 mag.—were measured in the microphotometer for 37 stars. The relation obtained in this way between microphotometer reading and differential stellar magnitude was used for the cluster plate. As will be seen below, the spectral intensities of the cluster are fairly near the same as of the stars B.D.+28°2259 and +27°2288. To find the differences in the distribution of energy in the spectra of the cluster and of these stars, therefore, only an approximate knowledge of the relation between microphotometer reading and stellar magnitude is needed. The determination of this relation by means of the north polar plate, as just described, is therefore sufficiently safe.

The results of the measures of the spectra of Messier 3 and of five selected stars in the neighborhood are given in Table I. The first column gives the distance in millimeters from the K line, the second the corresponding wave-length. The third column gives the magnitude equivalent of the density in the photograph of the spectrum of Messier 3, counted from an arbitrary zero point. The following columns give the corresponding figures for the five selected stars and their differences from those of Messier 3. When this difference is constant for all wave-lengths, it means that the spectral distribution of energy is the same in the cluster and in the star.

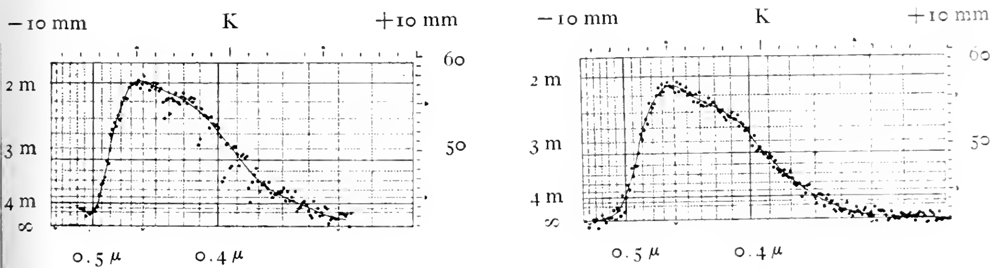
For reference, the graphical representation of the measures of the cluster and of the star B.D.+27°2288 are shown in the accompanying figure. On each of the two diagrams are the scale

TABLE I

Distance from K Line	Wave-Length A	Messier 3	+27° 2288 F3		+28° 2259 A4		+28° 2254 F1		+28° 2251* F1		+28° 2248 K1	
mm												
−8.0	5153	......	......	......	......	......	$4^{\mathrm{m}}.57$	......	......	......	$3^{\mathrm{m}}.78$	......
−7.5	5035	$4^{\mathrm{m}}.26$	$4^{\mathrm{m}}.44$	$-0^{\mathrm{m}}.18$	......	......	4.12	$+0^{\mathrm{m}}.14$	......	......	3.35	$+0^{\mathrm{m}}.91$
−7.0	4925	3.41	3.85	− .44	$4^{\mathrm{m}}.10$	$-0^{\mathrm{m}}.69$	3.05	+ .36	$4^{\mathrm{m}}.39$	$-0^{\mathrm{m}}.98$	2.29	+1.12
−6.5	4823	2.77	2.93	− .16	3.21	− .44	2.17	+ .60	3.46	− .69	1.54	+1.23
−6.0	4728	2.38	2.37	+ .01	2.56	− .18	1.56	+ .82	2.84	− .46	1.13	+1.25
−5.5	4638	2.18	2.10	+ .08	2.34	− .16	1.23	+ .95	2.53	− .35	0.96	+1.22
−5.0	4555	2.09	2.00	+ .09	2.18	− .09	1.13	+0.96	2.43	− .34	0.95	+1.14
−4.5	4476	2.11	2.00	+ .11	2.13	− .02	1.08	+1.03	2.40	− .29	1.05	+1.06
−4.0	4402	2.16	2.05	+ .11	2.13	+ .03	1.08	+1.08	2.42	− .26	1.22	+0.94
−3.5	4331	2.23	2.10	+ .13	2.16	+ .07	1.10	+1.13	2.47	− .24	1.47	+ .76
−3.0	4265	2.29	2.16	+ .13	2.21	+ .08	1.12	+1.17	2.49	− .20	1.70	+ .59
−2.5	4203	2.34	2.19	+ .15	2.27	+ .07	1.16	+1.18	2.54	− .20	1.88	+ .46
−2.0	4143	2.42	2.22	+ .20	2.35	+ .07	1.21	+1.21	2.61	− .19	1.98	+ .44
−1.5	4087	2.47	2.36	+ .11	2.42	+ .05	1.29	+1.18	2.68	− .21	2.03	+ .44
−1.0	4033	2.59	2.47	+ .12	2.50	+ .09	1.37	+1.22	2.75	− .16	2.14	+ .45
−0.5	3982	2.78	2.61	+ .17	2.61	+ .17	1.55	+1.23	2.85	− .07	2.53	+ .25
0.0	3934	2.96	2.78	+ .18	2.75	+ .21	1.70	+1.26	3.00	−0.04	3.16	− .20
0.5	3888	3.13	2.98	+ .15	2.94	+ .19	1.92	+1.21	......	......	3.62	− .49
1.0	3843	3.33	3.20	+ .13	3.18	+ .15	2.16	+1.17	......	......	4.16	− .83
1.5	3801	3.48	3.39	+ .09	3.46	+ .02	2.37	+1.11	......	......	4.08	− .60
2.0	3761	3.69	3.55	+ .14	3.72	− .03	2.68	+1.01	......	......	3.91	− .22
2.5	3722	3.89	3.68	+ .21	3.91	− .02	2.98	+0.91	......	......	4.25	− .36
3.0	3685	4.08	3.80	+ .28	4.12	− .04	3.29	+ .79	......	......	4.01	+ .07
3.5	3649	4.31	3.98	+ .33	4.31	.00	3.54	+ .77	......	......	4.16	+ .15
4.0	3615	4.56	4.11	+0.45	4.44	+0.12	3.86	+0.70	......	......	4.42	+0.14
4.5	3582	......	4.31	......	......	......	4.15	......	......	......	......	......
5.0	3550	......	4.47	......	......	......	4.50	......	......	......	......	......
5.5	3520	......	......	......	......	......	......	......	......	......	......	......
6.0	3491	......	......	......	......	......	......	......	......	......	......	......

* The shorter wave-lengths of +28° 2251 interfere with the spectrum of +29° 2452.

of wave-lengths indicated below, of magnitude corresponding to the density on the photograph to the left, of distances from the K line above, and of microphotometer readings to the right. The graphical smoothing of the measures of the star spectrum as described above will be seen in the figure. It may be noted that the UV Zeiss triplet has been so achromatized that the minimum focus lies about at the wave-length λ 3900, and light at λ 4800 is about 3 mm out of minimum focus. The great similarity in the spectral distribution of energy in the cluster and in the star B.D.+27°2288, in the region examined, is striking, especially



B.D.+27°2288 Messier 3

Fig. 1

between the wave-lengths λ 3761 (+2.0 mm from the K line) and λ 4555 (−5.0 mm), where the determination is best. At the longer wave-lengths the exactness may be affected by the quick change in the density of the spectrum and at the very shortest ones the density is so small that the measures become uncertain. There also the "head" of the hydrogen series may cause trouble. Light in the spectrum of the cluster is traced to about λ 3500.

The spectral types indicated in the table are derived from my estimates of the relative intensities of the K line and of the hydrogen lines. For the star +28°2248 the line λ 4227 was used.

Altogether it is seen that the distribution of energy in the integrated spectrum of Messier 3 between λ 3761 and λ 4555 is very nearly like that of a typical F star.

According to Mr. Fath (*Astrophysical Journal*, **33**, 62, 1911) the spectrum of Messier 3 lies between A and G. This agreement

between spectral lines and distribution of energy in the same part of the spectrum, where the lines for classification have been observed, does not indicate any sensible selective extinction of light in space.

Compared with the results of Mr. Babcock (footnote to J. C. Kapteyn, "Absorption of Light in Space," *Astrophysical Journal*, **30**, 316, 1909) on three other globular clusters, this conclusion is somewhat unexpected. I was therefore eager to get also visual comparisons of the integrated light of Messier 3 with some of the comparison stars used above. This has been accomplished in two ways. First I measured (June 29, 1914) with a small visual refractor ($a=13$, $f=210$ cm) how far I had to go out of focus to get the extrafocal disk of the cluster or of the comparison star of a certain estimated brightness in contrast to the background of the sky. This gave me: magnitude of Messier 3 minus magnitude of B.D.$+28°2254$ equal to $+0.31$ mag. (or the magnitude of Messier 3 is 7.06 mag.$+0.31$ mag.$=7.37$ mag. on the Harvard scale). Then, this result being somewhat uncertain, Professor Müller had the kindness to measure (June 30, 1914) the total brightness of the cluster with the short-focus photometers C1 and C2 (*Publ. Potsdam*, **17**, p. vii). The difference in magnitude against the star B.D.$+28°2254$ was found to be $+0.34$ mag. (or the magnitude of the cluster on the Potsdam scale is 7.28 mag.$+$ 0.34 mag.$=7.62$ mag.).

Assuming the visual measures to correspond with a wave-length of 5600 A, we then have the brightness of Messier 3 at different wave-lengths relative to certain stars as shown in Table II.

TABLE II

Wave-Length	Star Spectrum Vis. Mag. Harvard Vis. Mag. Potsdam	$+27°2288$ F3 — 8.24	$+28°2259$ A4 — 8.25	$+28°2254$ F1 7.06 7.28	$+28°2248$ K1 6.36 6.37
λ 3761		$+0.14$ mag.	-0.03 mag.	$+1.01$ mag.	-0.22 mag.
4555		$+0.09$	-0.09	$+0.96$	$+1.14$
5600		-0.63	-0.64	$+0.33$	$+1.13$

Hence Messier 3 is about 0.6 mag. brighter visually than a star showing the same spectral intensities as the cluster at λ 3761

and λ 4555. This difference may be due to a possible composite character of the integrated spectrum of the cluster. In fact for another cluster, Messier 13, Mr. Pease (*Carnegie Inst. Year Book*, 1913) found among 19 stars all steps between A and G. At any rate, in questions bearing on selective extinction of light in space the spectral class on one side and the distribution of energy on the other should at least be derived from an examination of the same region of the spectrum.

In addition to the foregoing it may be noted that the integrated light of the globular cluster Messier 15=N.G.C. 7078 is well measurable on the plates of the *Göttingen Actinometry*, in the scale of which I found its photographic magnitude to be 7.87 mag. The visual Harvard magnitude is 7.26 mag. (*Harv. Ann.*, **14**) and Professor Müller found the difference against the star B.D.+ 11°4573 to be -0.06 mag., hence the visual Potsdam magnitude of the cluster is $7.44-0.06=7.38$ mag.

The color-index we find from the Harvard measure to be mag. phot., Gött.$-$mag. vis. Harv.$=+0.61$ mag. and from the measure of Professor Müller $0.77\times0.49+0.27+0.04\times0.88=+0.68$ mag. (*Gött. Act.*, B, **25**, formula 2). This color-index corresponds to a star with spectrum G 4.

Concerning the integrated spectrum of Messier 15, Mr. Fath (*Lick Bull.*, **5**, 74, 1909) concludes that stars of the F type are predominant. The color-index corresponding to a star of this type averages $+0.32$ mag. Hence Messier 15 is about 0.34 mag. brighter visually than an F star of the same photographic magnitude. This agrees well enough with the corresponding result found above for Messier 3.

POTSDAM
July 30, 1914

OBSERVATIONS OF THE *GRUNDSPECTRA* OF ALKALI AND ALKALINE EARTH METALS

By EDGAR H. NELTHORPE

INTRODUCTORY

In 1908[1] Goldstein described a method by which he obtained line spectra of potassium, rubidium, and caesium which were totally different from the arc spectra of these elements and could not be arranged in series of the ordinary type. The new spectra were called *Grundspectra*, but, as Goldstein pointed out, some of the lines had previously been observed to occur in spark spectra in company with the ordinary series lines. In fact, all the new lines given for potassium by Goldstein have since been recorded in the potassium spark by Schillinger,[2] who used a spark between metallic potassium electrodes in an atmosphere of hydrogen. Goldstein's method therefore appeared in some cases to result in the complete isolation of the enhanced (spark) lines from the arc lines occurring in the ordinary arc or spark. In view of the fact that enhanced lines appear without the arc lines in the spectra of some of the stars, it seemed desirable to repeat Goldstein's observations of the metals of the alkali group, and, if possible, to extend them to some of the elements which are represented in stellar spectra. The elements studied during the present investigation were sodium, potassium, rubidium, calcium, strontium, and barium.

APPARATUS EMPLOYED

Goldstein's first types of apparatus[3] were such that the anode in an evacuated tube was completely covered with the solid salt, and the discharge followed a path between the salt and the walls of the tube. In this method, however, the light is not of such a nature that it can easily be examined with a spectrograph: first,

[1] *Astrophysical Journal*, **27**, 25, 1908.

[2] *Wien. Ber.*, **118**, II(*a*), 1909.

[3] *Verh. der deutsch. phys. Gesell.*, **12**, 426, 1910.

because it is not of a great enough intensity, and second, and more important, because the walls of the tube in most cases get covered very quickly with a thick deposit of a darkish color. Hence, the form of discharge tube adopted in the present investigation was somewhat after the fashion of Goldstein's later types; that is to say, an H-shape.

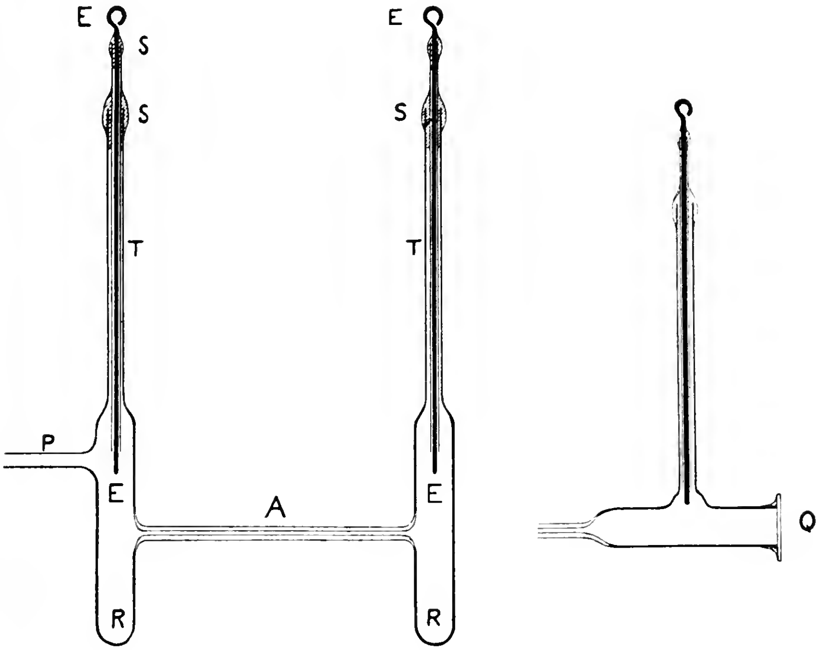


FIG. 1

The side tubes (R) were about 1.5 cm in diameter and were connected by a horizontal capillary tube (A) of 1 mm bore. Aluminium electrodes (E) were carried through the narrow connecting tubes (T) to which they were attached in the usual way with air-tight joints of sealing-wax (S). A small quantity of the powdered salt was placed at the bottom of each of the side tubes and could then be run into the capillary by a suitable manipulation of the tube. The end-on view of the tube is preferable, owing to the greater intensity of light obtained, and the spectrum may then be photographed down to about λ 3100; but if the broadside view

is taken, as is sometimes necessary, the spectrum does not reach beyond about λ 3400, on account of the greater thickness of the capillary tube as compared with the bulb. For wave-lengths still farther in the ultra-violet the tube may easily be modified to include a quartz window (*Q*). In all cases the tube was joined at *P* to a tube containing phosphorus pentoxide, and put into connection with a charcoal bulb, which could be cooled by liquid air, for the production of a high vacuum when desired. The drying tube is very necessary in the case of deliquescent salts, as when the substance is wet one obtains the spark spectrum of oxygen and hydrogen instead of that of the metal or halogen.

An induction coil giving at least a 10-inch spark would appear to be necessary. The condenser was joined across the secondary, and the tube and an air-gap were in series with one another but in parallel with the condenser. In most cases it was found necessary to use a larger coil giving a 12-inch spark, the primary taking anything up to about 10 amperes. With this coil a motor mercury-break was used. Under some conditions a small capacity and long air-gap were found to work best, while a large capacity and short air-gap gave better results in other cases.

POTASSIUM

The first substance investigated was potassium chloride. The solid salt in the bulb phosphoresces a beautiful violet, probably under the influence of cathode rays, and that in the capillary changes to a bluish-green color which may remain for weeks. With a sufficiently low pressure and a highly condensed discharge the capillary tube glows with a brilliant green light and in this case may be viewed end-on with advantage. The green coloration is due to the liberation of chlorine, and a preliminary examination of the spectrum might suggest that it was that of chlorine alone, as concluded by Goldstein.[1]

A closer examination, however, shows the presence of a number of other lines, some of which agree in position with lines given by Goldstein for potassium when the fluoride was used.

[1] Goldstein states that a condensed discharge with chlorides gives the chlorine spectrum alone, but with fluorides the *Grundspectrum* of the metal is obtained, the spectrum of fluorine being weak.

Most of the chlorine lines were easily identified, but some of those tabulated by Eder and Valenta seemed to be entirely absent, while a few others were greatly intensified.

Potassium bromide shows even more brilliance than the chloride when the discharge is passed, and the spectrum obtained is still more complicated, owing to the large number of lines in the bromine spectrum. By joining the two tubes together, the spectra of the chloride and bromide under the same experimental conditions were obtained as comparisons, and many of the potassium lines were thus easily distinguished.

The fluoride of potassium was found to be much more difficult to work with. In the first place, it must be carefully dried before use or one obtains nothing but lines of hydrogen and oxygen. Then, again, the end-on view was not permissible, as it always showed impurities such as air and carbon lines, and these usually predominated in the spectrum. The broadside view gave a purer spectrum, but the impurity lines were still present except in the near neighborhood of the most closely packed salt in the tube. A further difficulty was caused by the walls of the tube getting coated long before a reasonable exposure could be given. Nevertheless, many of the strongest potassium lines were recognized in the photographs taken.

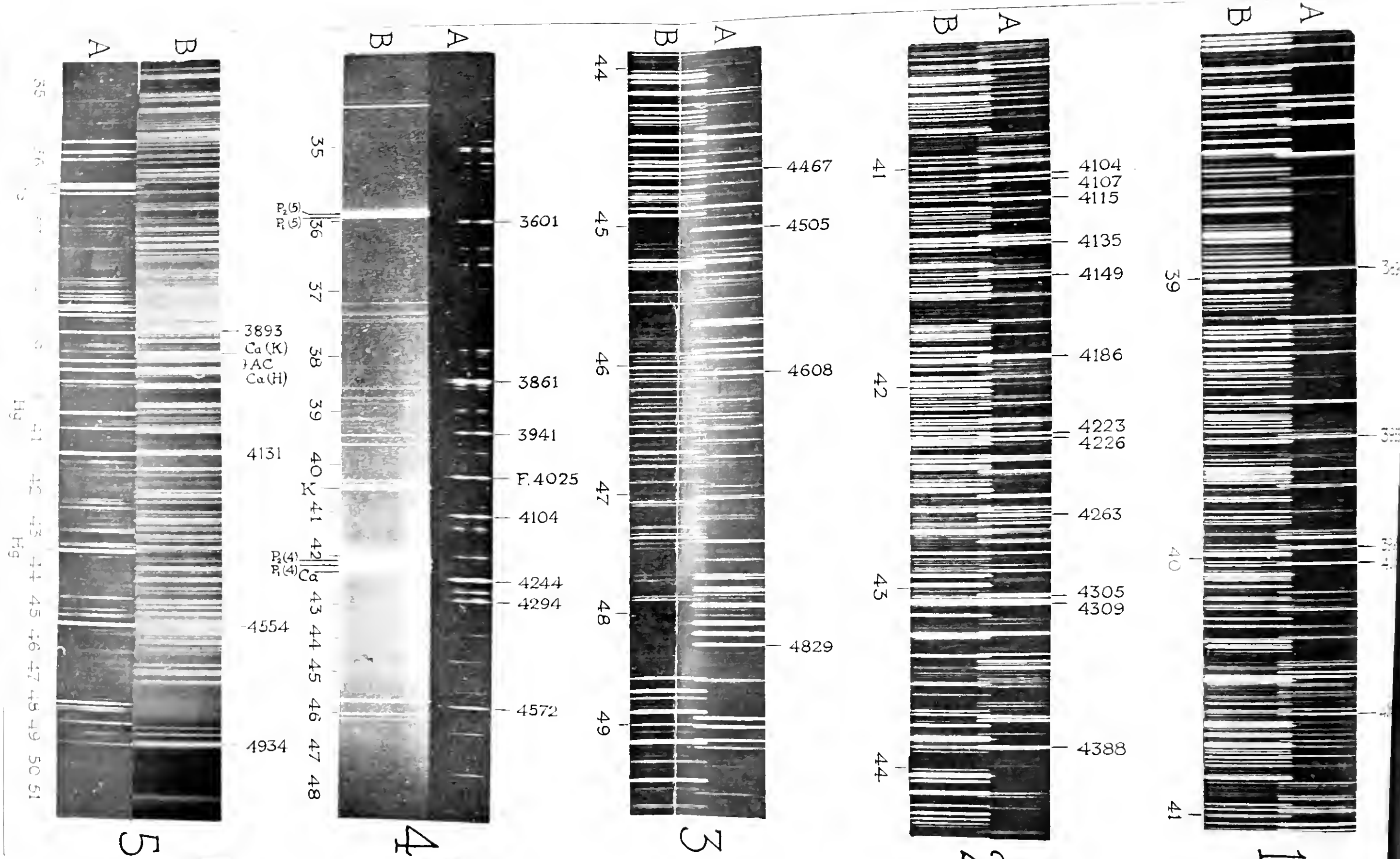
The plates obtained for the chloride were the best for the measurement of the potassium lines, as in the spectrum of the bromide many bromine lines fall in practically the same places as potassium lines, which therefore cannot be identified with certainty. A few of the stronger chlorine lines also usually occurred in the bromide spectrum, the chloride probably being an impurity.

Table I gives the wave-lengths of the stronger lines of the *Grundspectrum* of potassium down to λ 3900 as obtained from photographs taken with a single glass prism instrument mounted in the Littrow form. Goldstein's roughly approximate wave-lengths are indicated in the table, and Schillinger's wave-lengths for the potassium spark lines, with their intensities, are also given for comparison with those of the *Grundspectrum*. The entire absence of the principal series doublet at λ 4047 and λ 4044 from the *Grundspectrum* is very noticeable. In addition there were

TABLE I

Potassium

Grundspectrum			Spark	
Nelthorpe		Goldstein λ	Schillinger	
λ(I.A.)	Intensity		λ(Rowland)	Intensity
6307	3	630	6307.23	2
6247	1	624.5	6246.50	1
6120	8	611	6120.16	2
...	...	...	Subord. series lines	
5005.5	5	501	5005.52	2
4829.0	12	483	4829.17	2
...	...	...	4659.76	1
4607.7	15	461	4608.49	4
4505.3	8	451	4505.56	4
4466.6	5	447	4466.83	2
4423.7	1	...	4423.89	1
4388.2	10	439	4388.30	1
4339.9	5	...	4340.02	1
4309.1*	(?)	431	4309.24	5
4304.9	4		4305.17	3
...	...	...	4288.64	1
4263.2	10	526	4263.48	8
4225.6	6	422	4225.76	4
4222.9	8		4223.15	5
...	...	...	4210.37	1
4186.1	20	418	4186.39	10
4149.2	10	415	4149.39	5
4134.7	10	413	4134.87	5
4115.0	10	411	4115.11	3
4106.8	5	...	...	...
4104.2	7	...	...	...
4098.6	3n	...	...	...
4093.8	2	...	4094.53	1
4086.8	2	...	...	...
4075.6	3	...	...	...
4072.3	2	...	...	...
4069.3	1n	...	...	...
...	...	...	4066.64	1
4059.0	7	...	...	...
...	...	...	4048.10	2
...	...	...	4047.35†	10
...	...	...	4044.31†	20
4042.6	5	...	4042.81	2
...	...	...	4039.92	1
...	...	...	4025.35	1
4018.5	4	...	4018.26	1
4011.9	1	...	4012.22	1
4001.3	8	...	4001.35	5
3995.0	3n	...	3995.23	4
3972.5	4	...	3972.36	3



1, 2, 3. The spectrum of potassium chloride, with iron arc comparison. The chief potassium spark lines are marked. Case in which the end-on view is taken. A: potassium chloride, *Grundspectrum;* B: iron arc.

4. The spectrum of rubidium fluoride, showing practically only rubidium spark lines, with rubidium arc comparison. Case in which the broadside view is taken. A: rubidium, *Grundspectrum;* B: rubidium arc.

5. The spectrum of barium chloride fused into aluminium electrode, with barium arc comparison. A: barium chloride, *Grundspectrum;* B: barium arc.

TABLE I—*Continued*

Grundspectrum			Spark	
Nelthorpe		Goldstein λ	Schillinger	
λ(I.A.)	Intensity		λ(Rowland)	Intensity
3966.7	3	....	3966.90	3
3955.2	8	....	3955.42	7
3942.9	4n	....	3943.01	1
3934.5	1	....	3934.60	1
3926.8	2	....	3927.02	1
....	....	....	3923.80	1
3897.9	10	....	3898.01	8

* The line at λ 4309 falls in the same place as a chlorine line which is stronger in potassium chloride than in the chlorides of other metals and is therefore in part due to potassium.

† Arc doublet—$P_1(4)$ and $P_2(4)$.

a large number of both weak and strong lines in the ultra-violet which are not included in the table. Attempts to arrange the spark lines in series have, so far, been unsuccessful.

It will be observed that there is a very close accordance with Goldstein's observations in the region common to the two investigations, and that all but a few of the weakest lines of Schillinger's list appear in the *Grundspectrum*. A few lines which are not recorded by Schillinger in the potassium spark may possibly be enhanced lines of chlorine, which do not appear at all in the uncondensed discharge through chlorine in a vacuum tube.

RUBIDIUM

The only rubidium salt experimented with was the fluoride, but some interesting results were obtained. As with potassium fluoride, the end-on view showed a predominance of the lines of the gases present, such as carbon dioxide, water-vapor, and chlorine. When a broadside view was taken, however, at a point where the discharge was of a deep-blue color, the lines of rubidium were obtained, and the only other lines present were those due to fluorine, the spectrum of which consists of only a very few lines. The contrast between this spectrum and the arc spectrum of rubidium is very marked, as is shown in Plate I, No. 4.

The *Grundspectrum* appears only quite locally in the capillary tube, as was especially shown in one of the tubes in which the

rubidium fluoride was packed very tightly near one end. and only loosely at the other. A photograph taken with the tube end-on, first one end and then the other, showed a marked increase in the intensity of the lines of the metal, and a decrease in intensity of the lines of the gases present, at the end in which the salt was more closely packed.

As the spectrum was photographed with a quartz instrument of comparatively small dispersion, the wave-lengths could not be obtained very accurately. It soon became evident, however, that all the stronger lines were identical with lines observed in the spark by Exner and Haschek,[1] and the wave-lengths given by these observers have therefore been adopted. These are shown in Table II, together with the relative intensities in the spark and *Grundspectrum*. Other lines believed to belong to the *Grundspectrum* of rubidium, but not recorded in the spark, are shown in Table II*a*, the wave-lengths having been determined by interpolation with respect to neighboring lines given by Exner and Haschek.

SODIUM

With sodium chloride, the D lines appeared quite strongly, and the presence of spark lines, which are all faint, except those far in the ultra-violet,[2] was very doubtful. The color of the discharge was sometimes the green of chlorine and at others, the yellow of sodium. Thus, although it is possible that greater energy was put into the spark than that employed by Goldstein, the arc spectrum was still the predominant feature in the case of sodium.

The observations of the elements of the potassium group confirm Goldstein's conclusion that the heavier elements give the *Grundspectra* with the greater facility.

STRONTIUM

In the case of potassium, rubidium, and caesium, it appears that the *Grundspectra* consist only of the enhanced lines, which have not yet been arranged in series. It therefore seemed impor-

[1] *Wellenlängentabellen*, Leipzig und Wien: Funke, 1902.

[2] Eder and Valenta, *Denkschr. Wien. Akad.*, **61** (1894); R. Schillinger, *op. cit.*

tant to examine salts of the calcium group in the same way as in these cases. The enhanced lines are well known and most of

TABLE II

RUBIDIUM

Spark (Exner and Haschek)		Relative Intensities in *Grundspectrum* Max. = 10
Wave-Length	Intensity	
4648.75	2	1
4622.55	1	...
4571.75*	8	5
4530.50*	1	1
4378.1	1	1
4294.08*	10	5
4288.20	2	1
4273.26*	3	3
4244.50*	30	10
4215.73†	10	...
4201.97†	30	...
4193.18	3	3
4136.55	1	<1
4132.70	2	1
4104.49	10	5
4084.05	2	1
4029.65	1	1
3978.30	2	1
3940.62	20	5
3927.3	1	<1
3914.5	1	...
3861.40	5	2
3851.9	3	4
3846.3	2	...
3843.8	1	...
3833.94	1	...
3828.1	2	1
3806.0	1	1
3802.05	2	3
3796.99	3	3
3699.98	1	1
3664.4	1	2
3663.5	1	2
3640.55	1	1
3601.35	3	5
3532.2	1	1
3522.2	2	2
3492.5	1	1

* Also observed by Goldstein. † Arc doublet—$P_1(4)$ and $P_2(4)$.

them can be arranged in series which differ from ordinary arc line series only in the replacement of the series constant N by the term $4N$.[1]

[1] Fowler, *Phil. Trans. Roy. Soc.*, A **214**, 225, 1914.

The first substance investigated was strontium chloride. The discharge was of the green color characteristic of chlorides, but neither the end-on nor the broadside position showed any trace of strontium lines, and, in fact, one could not hope to get a purer chlorine spectrum than was obtained by photographing from the end-on position.

TABLE II*a*

RUBIDIUM

Wave-Length	Relative Intensity	Wave-Length	Relative Intensity
5526*	1	3866.5	1
5152*	1	3856.0	3
4777*†	2	3854.8	3
4267.3‡	1	3812.3	1
4186.5§	<1	3642.8	2
4117.5	<1	3512.4	2
4109.4	<1	3496.6	2
3867.6	1	3494.3	2

* Also observed by Goldstein.

† Given in a later table by Exner and Haschek, *Die Spectren der Elemente bei normalem Druck* (1911).

‡ Carbon(?). § Potassium(?).

An examination of the neighborhood of the tip of the electrode, however, showed the presence of the enhanced strontium line at λ 4216 to a very marked extent. Better results were subsequently obtained by fusing some of the salt on the electrode. This method is an approximation to that originally used by Goldstein, in which the anode was surrounded by the salt. The method was also tried with potassium, but no improvement on the previous results was obtained.

The photographs taken showed the strontium doublets, and only one other strontium line, viz., the strong flame and arc line at λ 4607, whose relative intensity, however, was much diminished. A few of the stronger chlorine lines and the aluminium spark lines also appeared in the spectrum.

Table III shows the extent to which the strontium spectrum became modified by this method.

CALCIUM

In the case of calcium, the fluoride was used, fused into the electrode in the same way as with strontium chloride. By far the

strongest lines in the spectrum were the H and K lines at λ 3969 and λ 3934, forming the first pair of the principal series of doublets. Other enhanced lines appearing were the sharp pair at λ 3737 and λ 3706, whose intensities were rather small, and the diffuse pair at λ 3179 and λ 3159, which appeared quite strongly. The strong arc lines at λ 3645 and λ 3631 totally disappeared, but the well-known flame and arc line at λ 4227 was still present but much decreased in intensity.

TABLE III

STRONTIUM

Grundspectrum		Intensity in Arc Exner and Haschek*	Series
Wave-Length	Relative Intensity		
4607	100	1000	(Arc line)
4306	40	20	Sharp
4216	500	500	Principal
4162	30	20	Sharp
4078	1000	1000	Principal
3475	20	8	Diffuse (Sat.)
3465	100	30	Diffuse
3381	100	20	Diffuse

* *Die Spectren der Elemente bei normalem Druck.*

On the whole, the phenomena with calcium were less striking than with strontium, but the general result was the same, namely, an approach to conditions under which the enhanced lines occur alone.

BARIUM

In the case of barium, the chloride was used and the results obtained with it were highly satisfactory. The discharge was very brilliant, and even with the 10-inch coil good photographs were obtained. All the spark doublets in the region covered by the photographs were observed, the lines at λ 4554 and λ 4131 being by far the strongest in the spectrum. The pair observed by Runge and Paschen[1] at λ 6497 and λ 5853, which have not yet been fitted into any of the series, was relatively weak.

Arc lines were practically absent, for it was only by making the discharge as brilliant as possible that the bright arc line at

[1] *Astrophysical Journal*, **16**, 133, 1902.

λ 5536 could be observed at all. Table IV shows how striking is the modification of the spectrum.

TABLE IV

BARIUM

Wave-Length	Intensity in Arc Exner and Haschek*	Intensity in Spark Exner and Haschek*	Intensity in *Grundspectrum* Max. = 1000	Series
6497..........	200	200	100	....
6142..........	1000	500	200	....
5853..........	200	100	50	....
5536..........	100	30	20	(Arc line)
4934..........	100	300	500	Principal
4900..........	10	100	200	Sharp
4554..........	1000	1000	1000	Principal
4525..........	10	50	200	Sharp
4283..........	20	20	....	(Arc line)
4166..........	10	100	200	Diffuse (Sat.)
4131..........	100	800	1000	Diffuse
3993..........	100	20	....	(Arc line)
3893..........	10	500	500	Diffuse

* *Spectren der Elemente bei normalem Druck* (1911).

Thus, with the calcium group of elements also, the greater the atomic weight of the metal, the greater the modification of the spectrum.

It may be stated that very brilliant phosphorescence effects are obtained with these salts, especially when the pressure is very low.

THE SPECTRUM OF CHLORINE

It is of interest to note that many of the vacuum-tube lines of chlorine and bromine as tabulated by Eder and Valenta[1] did not appear in the photographs of the chlorides and bromides examined. This is in accordance with Goldstein's[2] observation that some of the strong lines of chlorine and bromine disappear when a large capacity is introduced. The spectra of three or four chlorides having been thoroughly examined, the accompanying list of strong vacuum-tube chlorine lines missing from the spark spectrum of solid chlorides was obtained (Table V).

These lines appear to have been obtained only with weak discharges and doubtless correspond in some way to arc spectra in the case of metals.

[1] *Wien. Denkschr.*, pp. 68, 437, and 523, 1899. [2] *Op. cit.*

A few other lines were very much weakened in these spectra, but did not entirely disappear; notably the lines at λλ 4475.5, 4371.7, 4363.5, 4259.6, and 3868.8.

TABLE V

CHLORINE LINES NOT OBSERVED IN *Grundspectrum* TUBES

Wave-Length (Eder and Valenta)	Intensity in Vacuum Tube	Wave-Length (Eder and Valenta)	Intensity in Vacuum Tube
4624.23	3	4363.457	8
4601.19	4	4323.523	6
4526.44	5	4280.615	3
4475.498	4	4264.740	3
4469.569	5	4226.580	7
4438.735	4	4209.866	5
4403.610	5	4032.330	5
4390.566	3	3982.060	3
4389.949	8	3871.537	4
4369.676	6	3854.000	4

Again, several other lines were greatly intensified and probably correspond with the enhanced lines of metals. Among these was the strong characteristic triplet at λλ 4819.6, 4810.2, and 4794.6, besides lines at λλ 4132.7, 3991.6, and 3861.0.

GENERAL CONCLUSION

The chief conclusion to be drawn from the foregoing investigation is that the *Grundspectra* obtained by Goldstein's method consist essentially of lines which are specially developed in the ordinary spark spectrum. With potassium and rubidium, the spectra consist entirely of the enhanced lines, but with the calcium group the last traces of the arc spectrum have not yet been entirely removed. In this connection, it may be noted that the arc spectra of potassium and rubidium contain no spark lines, while in the arc spectrum of the calcium group the spark lines (e.g., the H and K lines of calcium) appear very strongly.

In conclusion, I wish to record my best thanks to Professor Fowler for valuable advice and help during the investigation and in the preparation of the paper.

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October 8, 1914

ANOMALOUS DISPERSION IN THE SUN IN THE LIGHT OF OBSERVATIONS[1]

By CHARLES E. ST. JOHN

In a series of recent articles[2] Professor Julius has considered the displacements of the Fraunhofer lines at the center and limb edges of eccentrically located sun-spots from the point of view of his theory of anomalous dispersion. For the subject-matter he has used the data published in my paper on "Radial Motion in Sun-Spots."[3] In these articles he sets forth a new deduction from the theory of anomalous dispersion—the "mutual influence" of the Fraunhofer lines upon each other: in particular, that a weak line on the violet side of, and near to, a stronger line is displaced less, but if on the red side more, than the average amount. This deduction offers a means of making a quantitative test of the rôle played by anomalous dispersion in the solar atmosphere. These displacements are well suited for a definitive test of the theory, for they are purely differential, and numerous other lines upon the same plates are available for standards of reference.

Professor Julius selected 82 lines from my published list of displacements at the outer edge of the penumbrae of spots, and he finds that those to the violet of stronger lines are displaced less, and those to the red more, than the average. There are, however, many other lines in my list that fulfil the conditions of selection proposed by Professor Julius. These give results opposite to those obtained from the lines selected by him. Moreover, his treatment of the data in obtaining the normal displacements appears to have involved an error, the effect of which is to introduce residuals of the sign required by his theory. These points will now be given consideration in detail. In such a discussion three things demand attention in order that no systematic errors may be introduced and that proper weight

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 93.

[2] *Versl. kon. akad. v. wetensch. Amsterdam*, **22**, 1243, 1914; *Observatory*, **37**, 252, 1914; *Astrophysical Journal*, **40**, 1, 1914.

[3] *Mt. Wilson Contr.*, No. 69; *Astrophysical Journal*, **37**, 327, 1913.

may be given to crucial cases whose bearing upon the question is of special importance: (1) the determination of the standard displacements; (2) the inclusion of all lines falling within the adopted conditions of selection; (3) consideration of the effects in the immediate neighborhood of strong lines showing in the laboratory marked anomalous dispersion phenomena.

STANDARD DISPLACEMENTS

The 506 lines of Table I in my first paper[1] do not form a homogeneous series of observations. Attention was called to this point in my discussion of the data. From this it results that the normal displacements for different spectral regions cannot be determined with high precision by deducing them for each region by any smoothing-out process involving the results for all the segregated regions. The following regions were covered by the observations:

a) From λ 3624 to λ 3724. Here a few plates were taken with the purpose of obtaining the line λ 3694 assigned by Jewell to ytterbium, as it began to appear probable that the heavy elements would be of particular interest.

b) From λ 3879 to λ 4410. This is a homogeneous region, as overlapping plates were obtained by which the observations were interconnected and hence are comparable.

c) From λ 4634 to λ 4829. The earlier observations were upon this region, as it was desired first to repeat Evershed's observations. The mean result for all lines in this region is high in comparison with regions on either side; and, of the six regions, it is the one in which the necessity of separate consideration is the greatest, when the behavior of individual lines is to be studied.

d) From λ 5123 to λ 5349. This region includes the great magnesium lines of the *b* group.

e) From λ 5598 to λ 6065, in order to obtain the D lines of sodium.

f) From λ 6393 to λ 6643, to include the H_α line of hydrogen.

To obtain the normal displacements, Professor Julius used the mean displacements for the iron lines grouped into three regions,

[1] *Mt. Wilson Contr.*, No. 69, p. 6; *Astrophysical Journal*, **37**, 333, 1913.

namely: the two violet series, mean λ 4017; the blue-green series, mean λ 4992; and the yellow-red series, mean λ 6121, reproduced in Table I.

TABLE I

DISPLACEMENTS OF IRON LINES

Region	Intensity							
	1	2	3	4	5	6	7	8
λ 4017	0.022	0.020	0.014	0.014	0.013	0.011	0.008	0.006
λ 4992	0.030	0.026	0.026	0.025	0.018	0.016	0.006	0.007
λ 6121	0.032	0.030	0.032	0.024	0.028	0.024	0.019	0.016

Using these data, he says:

. . . . On the basis of the two rules found by St. John that connect the displacements with line intensity and with wave-length, it was possible to indicate a "normal" displacement peculiar to the spectral region and the intensity of each measured line. With these normal values the observed values had to be compared.[1]

The method of derivation of the normal displacements is not explicitly stated, but supposedly they were obtained either graphically or analytically from the data given. In either case the derived values would depend upon, and be influenced by, the displacements in the separate regions and would not refer with high precision to any one of the homogeneous regions. The mean displacements for the iron and nickel lines of intensity 2–3 for each of the six spectral regions are plotted in Fig. 1, and the curve drawn with consideration of the weights of the points. Owing to the very large displacements given by the blue region, λ 4634–λ 4829, the normals for the adjoining regions, deduced from the data for all regions, are too large, and for the blue region itself too small. The use of normal displacements interpolated from such a graph might be justifiable, if the lines whose displacements are to be compared with these normals were well distributed over the regions concerned in their derivation. It is evident that if the lines whose displacements are to be compared with such normals are not evenly distributed, but are confined to one or two regions, systematic

[1] *Astrophysical Journal*, 40, 13, 1914.

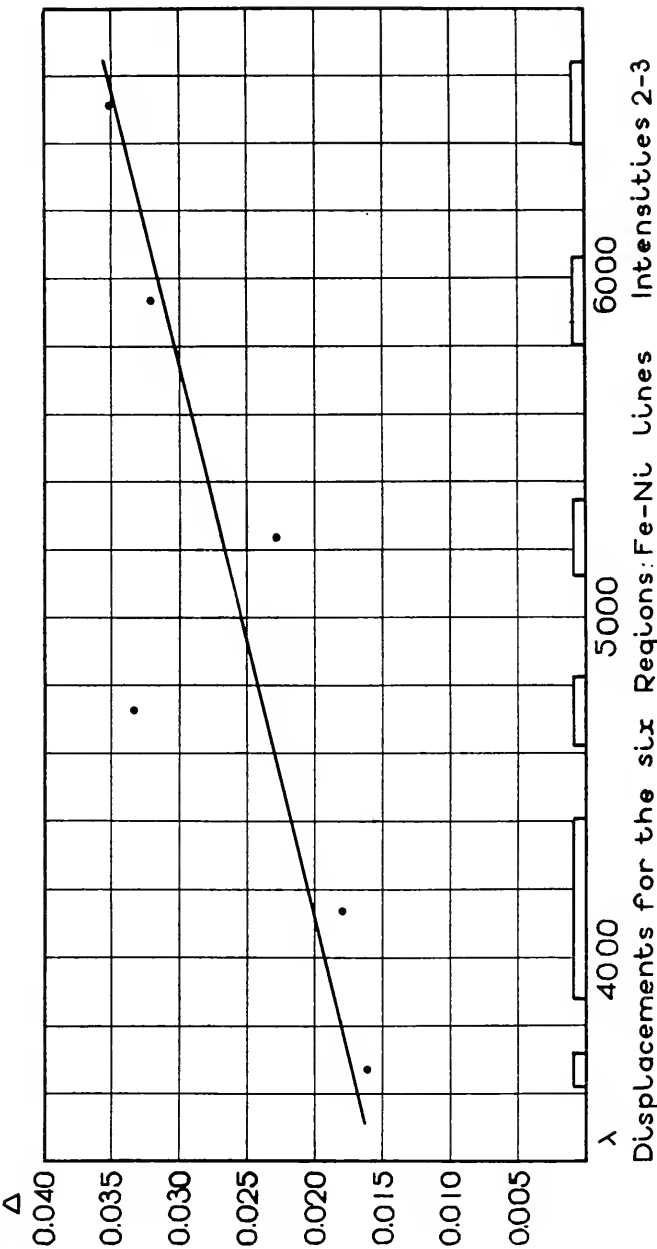

Δ
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
λ
4000
5000
6000
Displacements for the six Regions: Fe-Ni Lines Intensities 2-3

FIG. 1

residuals will result. Moreover, the normal displacements used by Professor Julius are derived from the displacements of the iron lines only. This neglects any differences depending upon individual elements, differences that are real and systematic.

To obtain residuals capable of representing any systematic behavior of lines within the refractive influence of stronger lines, the standard displacements should be derived from the limited homogeneous series of observations in which they are to be used, and, as far as the data permit, they should refer to the particular elements under consideration. Standard displacements of this character have been obtained by determining the mean displacements for the lines of each element of a given intensity for each of the six homogeneous series. In the rare cases where fewer than three lines are available, the mean displacement for all lines of the same intensity in the respective series has been used.

In the first section of Tables II and III are reproduced the data given by Professor Julius for lines on the violet and red sides of stronger lines, respectively. In the eighth column are shown the mean displacements for the lines of the elements of the intensity and region under consideration, and in the ninth the residuals obtained by using these means as standard displacements. In the last column are remarks relative to the character and properties of the influencing lines that bear upon their power to produce the assumed effects.

ADDITIONAL LINES

Attention has been called to the necessary condition that all lines within the definition of the category be included. Professor Julius says:

> . . . . I selected *all* cases in which a measured line *A* of intensity 3 or lower was on the *violet* side of a stronger line *B* (generally of intensity 4 or higher) at a distance of about 0.5 A or less. A few cases in which the line *A* had another strong companion *B′* equally near but on the other side were of course discarded. Forty-three pairs answering the conditions were found. . . . .[1]

After a definition has been adopted, it is always hazardous to disregard it. The lanthanum line, λ 3995, of intensity 1, is between

[1] *Astrophysical Journal*, **40**, 13, 1914.

two lines of intensities 3 and 5, each within the limiting distance of 0.5 A. It is a delicate question to decide whether the line of intensity 3, which is nearer, or the line of intensity 5 is the more influential. The measured displacement of this lanthanum line is small, 0.014 A. It is on the violet side of the weaker line and shows a large negative residual. The decision was in favor of the weaker. The lanthanum line λ4123 shows a large displacement, 0.023 A. It is 0.523 A to the violet of a much stronger line. It is omitted, though favorable cases exceeding the limit by much larger amounts are included. Of the 14 lines included by Professor Julius in which either the distance exceeds 0.5 A, or some one or more of the other limitations are exceeded, two only are unfavorable to the thesis under consideration.

It is a question whether the mutual influence of a blend is the same as that of a single line whose intensity is the sum of the intensities of the constituents; for example, it is at least doubtful whether a line of intensity 5 should be considered susceptible to the influence of a blend consisting of 2 lines each of intensity 3 to the same degree as of a single line of intensity 6, as Professor Julius has apparently done. However this may be, it seems clearly inadmissible to include the influenced line itself in the blend and particularly inadmissible when the influenced line forms the major part of the blend, for then we have the remarkable case of a line displaced by its own influence, as λ 3899.171.

An examination of Rowland's Table shows 49 lines not included by Professor Julius, 24 on the violet and 25 on the red side of stronger lines. Of these additional lines those on the violet are all within the limiting distance of 0.5 A; of those on the red, two exceed it. These two lines are now included, mainly because of their important bearing on the theory of anomalous dispersion: they are a line of intensity 4 at 0.7 A to the red of a line of intensity 20, and a line of intensity 10 at 0.79 A from a line of solar intensity 700. In both cases the anomalous dispersion of the controlling lines is strong and the lines are within the limits used by Professor Julius, as he included the Ni line λ 4703 of intensity 3 at 0.817 A from a line of intensity 10. For the additional lines the normal displacements given by Professor Julius are used for their respective

TABLE II A

FRAUNHOFER LINES TO THE VIOLET OF STRONGER LINES AS SELECTED BY PROFESSOR JULIUS

Lines	Difference	Element	Intensity	Observed Displacement	Julius		St. John		
					Normal Displacement	Residual	Mean	Residual	Remarks
3640.137		Cr	1	0.014	0.022	−0.008	0.018	−0.004	
3640.438	.301	...	5						
3662.096		Ni	3	.015	.015	.000	.015	.000	
3662.378	.282	(Ti)	5						
3686.926		Cr	1	.016	.022	− .006	.018	− .002	
3687.234	.308	....	3						
3687.234		Fe	3	.010	.015	− .005	.015	− .005	
3687.610	.376	Fe	6						
3688.210		V	1	.018	.022	− .004	.017	+ .001	
3688.558	.348	......	4						
3690.599		Fe	2	.017	.020	− .003	.016	+ .001	
3690.870	.271	......	3						
3707.702		Ti	2	.013	.020	− .007	.016	− .003	
3708.07	.366	Fe	6						
3708.964		Co	1	.015	.022	− .007	.018	− .003	
3709.389	.425	Fe	6						
3895.119		Co	3	.012	.015	− .003	.013	− .001	
Blend		....	4?						Blend of weak lines
3895.583		Mn	3	0.008	0.015	−0.007	0.017	−0.009	
3895.803	.220	Fe	7						Anomalous dispersion very weak

3898.032		Fe	3	0.007	0.015	−0.008	0.015	−0.008	
3898.2			4						Perhaps V5 at 3898.151
3899.171		Fe	3	.013	.015	− .002	.015	− .002	A line displaced by its own action as it forms the major portion of the influencing line
3899.21		(V-Fe)	3						
3906.438		Co	2	.010	.020	− .010	.016	− .006	
3906.628	.190	Fe	10						Anomalous dispersion very weak
3913.123		Ni	2	.016	.020	− .004	.019	− .003	
3913.609	.486	Ti	5						
3916.879		Fe	5	.009	.014	− .005	.014	− .005	
3917.324	.445	(Fe)	6						Intensity 5
3947.522		?	2	.014	.021	− .007	.019	− .005	
3947.675	.153	Fe	4						
3956.603		Fe	4	.010	.014	− .004	.014	− .004	
3956.879	.276	Fe	6						
3958.073		Co	2	.018	.022	− .004	.016	+ .002	
3958.355	.282	(Zr-Ti)	4						
3962.995		Ti	3	.012	.016	− .004	.012	.000	
3963.281	.286		4						Blend
3995.899		La	1	.014	.023	− .009	.022	− .008	On the other side is a line of intensity 5, 0.436 A distant, whose effect is neglected
3996.140	.241		3						
3997.115		Fe	2	.019	.022	− .003	.019	.000	
3997.547	.432	Fe	4						
4035.752		Co	2	0.016	0.022	−0.006	0.016	0.000	
4035.883	.131	Mn	4						Anomalous dispersion strong

TABLE II A—*Continued*

Lines	Difference	Element	Intensity	Observed Displacement	Julius: Normal Displacement	Julius: Residual	St. John: Mean	St. John: Residual	Remarks
4109.609		Nd	1	0.016	0.024	−0.008	0.022	−0.006	
4109.953	.344	....	4						Intensity 3
4132.100		V	2	.011	.022	− .011	.021	− .010	
4132.235	.135	Fe	10						
4133.755		Fe	2	.022	.022	.000	.019	+ .003	
4133.95	.255	(Fe-Ce)	4						Fe 3 at 4134.010
4149.360		Zr	2	.016	.022	− .006	.018	− .002	
4149.533	.173	Fe	4						
4216.136		CN	1	.022	.024	− .002	.018	+ .004	
4216.351	.215	(Fe)	4						Intensity 3
4233.328		(Mn-Fe)	4	.017	.017	.000	.014	+ .003	
4233.772	.444	Fe	6						
4271.325		Fe	6	.009	.014	− .005	.011	− .002	
4271.934	.609	Fe	15						Anomalous dispersion very weak
4274.746		Ti	2	.016	.023	− .007	.017	− .001	
4274.958	.212	Cr	7						Anomalous dispersion very strong
4289.525		Ca	4	.015	.019	− .004	.016	− .001	
4289.885	.360	Cr	5						Anomalous dispersion very strong
4294.936		Zr	2	.018	.023	− .005	.018	.000	
4295.29	.354	Dy	6						Dy? Blend
4302.353		Fe	2	0.019	0.023	−0.004	0.019	0.000	
4302.692	.339	Ca	4						Anomalous dispersion very weak

4315.138		Ti	3	0.010	0.021	−0.011	0.012	−0.002	
4315.262	.124	Fe	4						
4408.364		V	2	.027	.024	+ .003	.021	+ .006	
4408.54	.218	(V)	4						Fe 3 at 4408.582
5168.832		Ni	1	.026	.028	− .002	.028	− .002	
5169.16	.323	(Fe)	7						Blend
5188.863		Ti	2	.015	.026	− .011	.019	− .004	
5189.018	.155	Ca	3						
5226.707		Ti	2	.020	.026	− .006	.019	+ .001	
5227.043	.336	Fe-Cr	4						Intensity 3
5250.385		Fe	2	.028	.027	+ .001	.023	+ .005	
5250.817	.432	(Fe)	3						
5298.194		Cr	1	.021	.029	− .008	.024	− .003	
5298.455	.261	Cr	4						Anomalous dispersion weak
5598.524		Fe	1	.019	.030	− .011	.025	− .006	
5598.711	.187	Ca	4						Anomalous dispersion very weak
5615.520		Fe	2	.025	.027	− .002	.023	+ .002	
5615.877	.357	Fe	6						
5624.245		Fe	1	0.027	0.031	−0.004	0.025	+0.002	
5624.769	.524	(Fe)	4						
Mean						−0.0051A		−0.0018A	

TABLE II B

ADDITIONAL LINES TO THE VIOLET OF STRONGER LINES

Lines	Difference	Element	Intensity	Observed Displacement	Julius: Normal Displacement	Julius: Residual	St. John: Mean	St. John: Residual	Remarks
3630.045		Ni	1	0.024	0.022	+0.002	0.018	+0.006	
3630.492	.447	Fe	4						
3692.364		V	1	.017	.022	− .005	.017	.000	
3692.790	.426	Fe	2						
3692.790		Fe	2	.020	.020	.000	.016	+ .004	
3692.170	.380	Fe	3						
3895.377		Ti	2	.020	.020	.000	.017	+ .003	
3895.803	.426	Fe	7						
3897.596		Fe	2	.009	.020	− .011	.019	− .010	
3898.032	.436	Fe	3						
4006.304		Ni	1	.024	.023	+ .001	.024	.000	
4006.464	.160	Fe	2						
4006.464		Fe	2	.020	.022	− .002	.019	+ .001	
4006.776	.312	Fe	3						
4024.726		Ti	3	.016	.015	+ .001	.012	+ .004	
4024.881	.155	Fe	4						
4070.431		Mn	3	.023	.016	+ .007	.017	+ .006	
4070.930	.499	Fe	4						
4111.509		Ce	1	.028	.024	+ .004	.022	+ .006	
4111.940	.431	V	4						
4136.678		Fe	4	0.023	0.014	+0.009	0.014	+0.009	
4137.156	.478	Mn	6						

4183.480.....		Zr	1	0.024	0.024	0.000	0.021	+0.003	
4183.619.....	.139	V	2N						
4195.006.....		Cr	1	.020	.024	− .004	.021	− .001	
4195.492.....	.486	Fe	5						
4277.544.....		Zr	0	.026	.025	+ .001	.020	+ .006	
4277.692.....	.148	....	2d?						
4284.838.....		Ni	1	.030	.024	+ .006	.024	+ .006	
4285.164.....	.326	Ti	2						
4289.237.....		Ti	2	.022	.023	− .001	.017	+ .005	
4289.525.....	.288	Ca	4						Anomalous dispersion very weak
4314.964.....		Ti	1	.025	.024	+ .001	.023	+ .002	
4315.138.....	.174	Ti	3						
4377.948.....		Fe	1	.030	.024	+ .006	.022	+ .008	
4378.419.....	.471		2Nd?						
4708.846.....		Ti	2	.031	.024	+ .007	.032	− .001	
4709.271.....	.425	Fe	3						
4752.289.....		Ni	2	.040	.024	+ .016	.037	+ .003	
4752.613.....	.324	Ni	3						
4756.300.....		Cr	2	.026	.024	+ .002	.032	− .006	
4756.705.....	.405	Ni	3						Anomalous dispersion ?
4789.528.....		Cr	2	.034	.024	+ .010	.032	+ .002	
4789.849.....	.321	Fe	3						
5148.222.....		Fe	2	.023	.024	− .001	.023	.000	
5148.410.....	.188	Fe	3						
6496.688.....		Fe	2	0.037	0.031	+0.006	0.033	+0.004	
6497.128.....	.440	Fe	4						
Mean....	....	....	....	....	....	+0.0023A	....	+0.0025A	

TABLE III A

FRAUNHOFER LINES TO THE RED OF STRONGER LINES AS SELECTED BY PROFESSOR JULIUS

Lines	Difference	Element	Intensity	Observed Displacement	Julius: Normal Displacement	Julius: Residual	St. John: Mean	St. John: Residual	Remarks
3694.24	.209	(Fe-Ni)	8						Blend of intensity 6 at 3694.135
3694.344		Yt	3	0.020	0.015	+0.005	0.015	+0.005	
3694.344	.232	Yt	3						
3694.576		La	1	.027	.022	+ .005	.018	+ .009	
3704.603	.239	Fe	4						
3704.842		V	1	.016	.022	− .006	.018	− .002	
3706.24	.188	(Mn-Ti-Ca)	7						Intensity 6 at 3706.175
3706.363		Fe	3	.017	.015	+ .002	.015	+ .002	
3711.364	.188	Fe	4						
3711.552		Fe	3	.015	.015	.000	.015	.000	
3898.2	.380	....	4						V5 at 3898.151
3898.531		Mn	2	.014	.020	− .006	.020	− .006	
3947.675	.243	Fe	4						
3947.918		Ti	2	.013	.021	− .008	.017	− .004	
3948.925	.114	Fe	4						
3949.039		Ca	1	.018	.022	− .004	.022	− .004	
3950.102	.395	Fe	15?						Intensity 5
3950.497		Y	5	.013	.014	− .001	.014	− .001	
3984.17	.203	(Fe-Mn)	6						The influenced line is a part of the blend
3984.294		Mn	2	.021	.020	+ .001	.020	+ .001	
3989.912	.099	Ti	4						
3990.011		Fe	3	0.012	0.015	−0.003	0.015	−0.003	

4018.25	.164	(Mn)	7	....	....	....	....	....	Blend at 4018.256
4018.420		Fe	3	0.022	0.015	+0.007	0.015	+0.007	
4078.49	.116	?	4	....	....	....	....	....	Fe 4 at 4078.515
4078.631		Ti	3	.017	.016	+ .001	.012	+ .005	
4079.4	.200	....	5	....	....	....	....	....	Blend of Mn 3 and Fe 2 at 4079.370
4079.570		Mn	3	.018	.016	+ .002	.017	+ .001	
4134.54	.300	(V-Fe)	6	....	....	....	....	....	Blend of two lines of intensity 3
4134.840		Fe	5	.014	.014	.000	.014	.000	
4161.682	.279	(Ti)	5	....	....	....	....	....	Intensity 4
4161.961		Sr	1	.025	.024	+ .001	.022	+ .003	
4184.32		(Ti-Gd)	5	....	....	....	....	....	The influenced line is a part of the blend
4184.472		Ti	2	.022	.022	.000	.017	+ .005	
4196.35	.327	?	4	....	....	....	....	....	Fe 4 at 4196.372
4196.699		La	2	.024	.022	+ .002	.019	+ .005	
4236.112	.317	Fe	8	....	....	....	....	....	Anomalous dispersion very weak
4236.429		Ni	1	.024	.024	.000	.024	.000	
4240.64	.332	(Zr-Ce-Fe)	4	....	....	....	....	....	Intensity 2 at 7240.540
4240.872		Cr	1	.022	.024	− .002	.021	+ .001	
4338.084	.346	Ti	4	....	....	....	....	....	
4338.430		Fe	1	.025	.024	+ .001	.022	+ .003	
4637.685	.508	Fe	5	....	....	....	....	....	
4638.193		Fe	4	.027	.021	+ .006	.029	− .002	
4667.626	.142	Fe	4	....	....	....	....	....	
4667.768		Ti	3	.027	.023	+ .004	.030	− .003	
4679.027	.382	Fe	6	....	....	....	....	....	
4679.409		Ni	2	.037	.024	+ .013	.037	.000	
4703.177	.817	Mg	10	....	....	....	....	....	
4703.994		Ni	3	.035	.023	+ .012	.034	+ .001	
4731.651	.333	(Fe)	4	....	....	....	....	....	
4731.984		Ni	1	0.030	0.026	+0.004	0.036	−0.006	

TABLE III A—*Continued*

Lines	Difference	Element	Intensity	Observed Displacement	Julius: Normal Displacement	Julius: Residual	St. John: Mean	St. John: Residual	Remarks
4736.963...	.577	(Fe)	6						
4737.540...		Cr	2	0.034	0.024	+0.010	0.032	+0.002	
4762.567...	.253	Mn	5						Anomalous dispersion?
4762.820...		Ni	1	.039	.026	+ .013	.036	+ .003	
5129.42....		(Ti-Ni)	5						The influenced line is a part of the blend
5129.546...		Ni	2	.026	.024	+ .002	.024	+ .002	
5129.546...	.259	Ni	2						
5129.805...		Fe	1	.033	.028	+ .005	.028	+ .005	
5131.642...	.300	(Fe-C)	3						Intensity 2
5131.942...		Ni	1	.029	.028	+ .001	.028	+ .001	
5152.087...	.274	(Fe-C)	3						
5152.361...		Ti	0	.031	.031	.000	.027	+ .004	
5192.523...	.616	(Fe-Nd)	5						
5193.139...		Ti	2	.021	.026	− .005	.019	+ .002	
5283.802...	.479	(Fe)	6						
5284.281...		Ti	1	.026	.028	− .002	.028	− .002	
5298.455...	.217	Cr	4						Anomalous dispersion weak
5298.672...		Ti	1	.022	.028	− .006	.028	− .006	
5349.652...	.276	Ca	4						
5349.928...		Fe	1	.027	.028	− .001	.028	− .001	
5857.674...	.302	Ca	8						
5857.976...		Ni	3	.030	.027	+ .003	.032	− .002	
5953.0.....		(Ti-Fe)	5						The influenced line is a part of the blend
5953.386...		Ti	1	.038	.032	+ .006	.038	.000	
6400.217...	.311	Fe	8						
6400.528...		Fe	2	0.026	0.031	−0.005	0.035	−0.009	
Mean...	....	....	......	....	....	+0.0014Å	....	+0.0004Å	

TABLE III B

ADDITIONAL LINES TO THE RED OF STRONGER LINES

Lines	Difference	Element	Intensity	Observed Displacement	Julius: Normal Displacement	Julius: Residual	St. John: Mean	St. John: Residual	St. John: Remarks
3623.925	.333	Mn-Fe	4						
3624.258		Ca	3	0.012	0.015	−0.003	0.015	−0.003	
3645.967	.368	Fe	4						
3646.335		Ti	1	.012	.022	− .010	.018	− .006	
3693.170	.446	Fe	3						
3693.616		Co	1	.021	.022	− .001	.018	+ .003	
3724.526	.444	Fe	6						
3724.970		Ni	1	.018	.022	− .004	.018	.000	
3900.681	.433	Ti-Fe-Zr	5						
3901.114		Ti	1	.017	.023	− .006	.023	− .006	
3968.625	.788	Ca	700						Anomalous dispersion strong
3969.413		Fe	10	.004	.003	+ .001	.003	+ .001	
3984.091	.388	Cr-Fe	7						
3984.479		Cr	2	.024	.022	+ .002	.024	.000	
3991.333	.247	Cr-Zr	3						
3991.580		Fe	1	.020	.023	− .003	.022	− .002	
3992.971		V-Cr	3						
3993.246	.275	Fe	2	.025	.022	+ .003	.019	+ .006	
4020.424	.123	....	2						
4020.547		Sc	1	.014	.023	− .009	.022	− .008	
4023.533	.301	Co	3						
4023.834		Sc	2	.026	.022	+ .004	.020	+ .006	
4118.708	.226	Fe	5						
4118.934		Co	4	0.013	0.015	−0.002	0.015	−0.002	

TABLE III B—*Continued*

Lines	Difference	Element	Intensity	Observed Displacement	Julius: Normal Displacement*	Julius: Residual	St. John: Mean	St. John: Residual	Remarks
4137.567....	.242		2						
4137.809....		Fe, Ce	1	0.014	0.024	−0.010	0.022	−0.008	
4150.411....	.197		4						
4150.608....		Co	1	.017	.024	− .007	.022	− .005	
4196.699....	.138	La	2						
4196.837....		Fe	1	.020	.022	− .002	.022	− .002	
4224.673....	.347	Cr-Fe	3						
4225.020....		Cr	2	.021	.023	− .002	.022	− .001	
4226.904....	.702	Ca	20						Anomalous dispersion very strong
4227.606....		Fe	4	.010	.017	− .007	.014	− .004	
4261.891....	.251		2						
4262.142....		Cr	1	.024	.024	.000	.022	+ .002	
4273.482....	.161	Fe	3N						
4273.643....		Zr	2N	.021	.023	− .002	.020	+ .001	
4289.885....	.492	Cr	5						Anomalous dispersion very strong
4290.377....		Ti	2	.013	.023	− .010	.017	− .004	
4295.914....	.130	Cr-Ti	2						
4296.044....		Ni	1	.020	.024	− .004	.024	− .004	
4304.729....	.153		2						
4304.882....		Zr	0	.020	.025	− .005	.020	.000	
4359.784....	.123	Cr	3						Anomalous dispersion very weak
4359.907....		Zr	0	.019	.025	− .006	.020	− .001	
4400.555....	.183	Sc	3						
4400.738....		V	1	.021	.024	− .003	.022	− .001	
4786.727....	.276	Ni	3						
4787.003....		Fe	2	0.025	0.024	+0.001	0.030	−0.005	
Mean....	....	....	......	....	....	−0.0034A	....	−0.0017A	

intensities and spectral regions. In a few cases in which a direct transfer could not be made, the normals are interpolated from those used by Professor Julius.

The negative residual of −0.0051 A found by Professor Julius for the 43 lines to the violet is reduced to −0.0018 A when the displacement for each line is compared with the mean for the element, intensity, and region; but if all lines to the violet are taken into account, the corresponding mean residuals are −0.0024 A and −0.0003 A. When all lines to the red of stronger lines are considered, the mean residual is practically zero whichever standard is used. The results are assembled in Table IV.

TABLE IV

RESIDUALS GIVEN BY WEAK SOLAR LINES NEAR STRONGER LINES

Lines to Violet	According to Julius	According to St. John	Lines to Red	According to Julius	According to St. John
43 original........	−0.0051	−0.0018	39 original........	+0.0014	+0.0004 A
24 additional......	+ .0023	+ .0025	25 additional.....	− .0034	− .0017
Weighted mean	−0.0024	−0.0003	Weighted mean	−0.0005	−0.0004

A comprehensive impression may be obtained by combining the residuals derived in this paper as in Table V.

TABLE V

	Lines to Violet	Lines to Red	Total
Sum of favorable residuals..............	−0.125	+0.087	0.212 A
Sum of unfavorable residuals............	+0.105	−0.113	.218
Unfavorable excess from 131 lines........	....	....	.006
Mean excess per line...............	....	....	0.00005

This confirms the conclusion expressed in my second paper on "Radial Motion in Sun-Spots" that until we are able to depend upon solar wave-lengths to the fourth decimal place, at least, the contribution of anomalous dispersion to the relative positions of Fraunhofer lines, if any, will be masked by phenomena due to other causes.

SYSTEMATIC ERRORS

The results obtained by Professor Julius will now be discussed in the light of the systematic errors that appear to have been introduced by the method used by him in obtaining the normal displacements.

By referring to the graph in Fig. 1, or to a somewhat similar graph in the paper by Professor Julius,[1] it will be seen that normal displacements derived by combining the observations of the six series are too high for the violet and green regions because of the very large displacements given by the blue region, λ 4634–λ 4829.

In Table VI are given the residuals obtained by comparing the normal displacements used by Professor Julius with the mean displacements of all lines of the corresponding intensities in the respective regions.

TABLE VI

Comparison of the Julius Normals with the Means for All Lines of Like Intensity

Region	Intensity	Means	Normals	Residuals	Mean
Violet	1	0.0205	0.0220	−0.0015 A	−0.0022 A
	2	.0182	.0218	− .0036	
	3	.0147	.0159	− .0012	
	4	.0140	.0167	− .0027	
Blue	1	.0376	.026	+ .0116	+ .0093
	2	.0322	.024	+ .0082	
	3	.0334	.023	+ .0104	
	4	.0281	.021	+ .0071	
Green	1	.0275	.0285	− .0010	−0.0024
	2	0.0225	0.0263	−0.0038	

Of the 43 lines on the violet side of strong lines, 35 are in the violet region and 8 in the green, so that for these lines the residuals must of necessity be systematically negative, and this accounts in great part for the mean negative residual of −0.0051 A. Of the 24 additional lines, 19 are in the violet and green regions, so that of the 67 lines on the violet side of stronger lines 62 are in the regions where the normals derived from a consideration of the displacements

[1] *Astrophysical Journal*, **40**, 23, Fig. 6, 1914.

for all regions are too high; and the systematic errors introduced account for the final negative value -0.0024 A, when such normals are used, for it is evident from Table VI that any large group of lines selected at random from the violet and green regions must yield a mean negative residual of about -0.0023 A.

On the other hand, of the 39 lines on the red side of stronger lines some occur in each spectral region and the systematic residuals are less in evidence because of the more even distribution of the lines. It is illuminating, however, to consider them somewhat in detail. Of the 39 lines 7 are in the blue region, λ 4634–λ 4829, where the derived normals are too small and hence the residuals are necessarily positive. In fact, for these 7 lines the sum of the residuals is $+0.063$ A, while for the other 32 lines the sum is -0.005 A. It is evident from Table VI that a few lines from the blue region will furnish positive residuals sufficient to overbalance the negative residuals that the other 32 lines yield. It is equally evident that no weight can be given to these seven positive residuals of mean magnitude $+0.009$ A when the 22 other lines of the same elements and intensities in this region that are not on the red side of stronger lines give a mean residual of $+0.009$ A, precisely the same as that given by the lines within the limiting distance of stronger lines. In fact, it is impossible to select 7 lines from the 29 of the same elements and intensities that would not give a mean positive residual irrespective of their distance from stronger lines. When all the lines to the red are taken into the reckoning, they are fairly well distributed, and when so large a number is involved, the errors introduced by the normal displacements used by Professor Julius cease to be systematic and the positive residual disappears.

MUTUAL INFLUENCE AND LABORATORY RESULTS

The third point requiring attention is whether the mutual influence exerted by a strong line on a weak one in the solar atmosphere varies with the amount of anomalous dispersion manifested by the strong line under terrestrial conditions. The exaggerated importance ascribed to the possible effects of anomalous dispersion

in the solar atmosphere apparently arose from the fact that anomalous dispersion was first studied in the laboratory with the D lines of sodium which show it to an enormous degree, and the suggestion that such a phenomenon must be of influence in the solar atmosphere seemed to foreshadow great possibilities. Later investigation has shown that the anomalous dispersion possessed by the two sodium lines is exceptional and that few lines show it to a marked degree. Geisler has investigated some 300 lines belonging to 25 elements and found the following results:[1]

	Anomalous Dispersion					
	Very Strong	Strong	Medium	Weak	Very Weak	?
No. of lines........	9	17	34	80	123	36

The effect in the case of the sodium lines is so large that they cannot be included in a scale adjusted to the other lines. In view of the rarity of strong anomalous dispersion, it seems probable that the effect, in the few cases where weak lines are under the influence of strong lines showing anomalous dispersion to a high degree, would stand out clearly in contrast to the instances where the anomalous dispersion of the influencing line is unknown or very weak. It was with such a comparison in view that care was taken to include among the additions the line of intensity 4 at 0.7 A to the red of the line λ 4226.9 of calcium, intensity 20, which shows very strong anomalous dispersion, and the iron line λ 3969 of intensity 10 which is 0.788 A to the red of the H line of calcium, intensity 700. This calcium line has strong anomalous dispersion, and its "dispersion band" is some 10 or 12 A broad. Professor Julius has given an explanation of the calcium flocculi, of the progressive changes in the wave-lengths of the H and K lines in passing from the center to the limb, and of the great wings of these lines, based upon their anomalous dispersion. It would seem that the neighborhood of such lines is precisely the place where the mutual influence would manifest itself, and any failure here bears heavily

[1] *Zeitschrift für wissenschaftliche Photographie*, **7**, 89, 1909.

against the theory. There are 5 Fe lines of intensity 10 measured in the violet region, namely:

λ	Radial Displacement	
3906	0.003 A	
3969	0.004	0.79 A to red of calcium H, intensity 700
4132	0.002	
4260	0.003	
4404	0.003	
	0.003 A	

The remarkable thing is not the divergence in the displacements, but the extraordinary agreement. The iron line λ 4227 of intensity 4 is 0.7 A to the red of the calcium line 4226.9 of intensity 20. The calcium line shows very strong anomalous dispersion, but the residual for the iron line is −0.007 A or −0.004 A, according to whether the normals of Professor Julius or the means for Fe lines of intensity 4 in this region are used as standards of reference.

The comparative behavior of weak lines under the influence of strong lines showing great anomalous dispersion, and of those under the influence of strong lines showing weak and very weak anomalous dispersion, would seem to be of great importance and to deserve particular attention in the effort to establish a theory of mutual influence depending upon anomalous dispersion.

The data for such lines appear in Table VII, where the means show no systematic variation in the residuals depending upon the extreme differences in the anomalous dispersion exhibited by the influencing lines under laboratory conditions; and as there is no systematic difference between these residuals and those involving all the lines, it appears that the influencing lines showing either great or small anomalous dispersion produce neither more nor less effect than those manifesting it in a moderate degree.

ADDITIONAL MEASUREMENTS

So far the criterion of mutual influence has been applied only to the data given by the 506 lines of my original table. Since the announcement of the deduction of mutual influence new measures have been made upon the plates. In making the original series of

measurements, lines in the near neighborhood of very strong lines were in general omitted from the observing program, but in the case of elements represented by few lines, these were measured wherever found. In this new series the measures have been extended to all lines in the near neighborhood of strong lines showing great anomalous dispersion. The measurements have been

TABLE VII

ANOMALOUS DISPERSION OF INFLUENCING LINES

λ	Very Strong and Strong		λ	Weak, Very Weak, and ?		
	Julius	St. John		Julius	St. John	
4035...	−0.006	0.000	3895..	−0.007	−0.009	
4274...	− .007	− .001	3906..	− .010	− .006	
4289...	−0.004	−0.001	4271..	− .005	− .002	To the violet of stronger lines
			4289..	− .001	+ .005	
			4302..	− .004	.000	
			4756..	+ .002	− .006	
			5298..	− .008	− .003	
			5598..	−0.011	−0.006	
Mean	−0.0057	−0.0007	....	−0.0055	−0.0034	
3969...	+0.001	+0.001	4236..	0.000	0.000	
4227...	−0.007	−0.004	4290..	− .010	− .004	
			4359..	− .006	− .001	To the red of stronger lines
			4762..	+ .013	+ .003	
			5298..	− .006	− .006	
			5857..	+0.003	−0.003	
Mean	−0.0030	−0.0015	....	−0.0010	−0.0018	

made only upon a few plates of the best quality and include many lines extremely difficult to measure with precision, so that large accidental variations may be expected and the statistical method must be relied upon to determine probable results.

A few observations have also been made upon a large symmetrical spot that appeared on the eastern limb of the sun August 13, 1914. Measures of these plates are combined with those from the first series and are given in Tables VIII and IX. The displacements of 144 lines have been measured, of which 16 are within 1 A of the

very strong lines showing great anomalous dispersion. For standards of reference the mean displacements for all lines of a given intensity were used. For each line within 1 A of the strong lines, there are, on an average, 8 lines of the same intensity beyond this limit, upon which the standard displacement depends. If mutual influence produces a measurable effect, this effect should be increasingly manifest as the influencing lines are approached and should reach its maximum value in their near neighborhood. Within 1 A of these strong lines there are 8 lines to the violet showing a mean residual of +0.0006 A based upon 51 measures; there are 8 lines to the red showing a mean residual of +0.0003 A based upon 62 measures. The result then is practically zero, and it seems improbable that an effect of the order assumed by Professor Julius could fail to give an indication of its presence. The results given in Tables VIII and IX show no systematic variation as one approaches the influencing lines, nor any systematic difference between the displacement of lines on the violet and red sides of the strong lines. Observations will be made during the approaching spot maximum upon a larger number of spots, with particular attention to lines under the possible influence of stronger lines, and the mass of data greatly increased; but as far as the present observations are concerned, they fail to show a dependence of mutual influence upon the intensity of the controlling lines, upon their power to produce anomalous dispersion effects, or upon the nearness of the influenced lines.

ANOMALOUS DISPERSION IN THE LABORATORY AND IN THE SUN

The following extract from one of the earlier papers of Professor Julius gives the idea that he himself was at that time under the impression that a straightforward comparison could be made between laboratory results for anomalous dispersion and solar phenomena:

> A careful examination of the anomalous dispersion of a great number of substances will, of course, have to be made before it can be made out in how far our view will account for the facts already known or yet to be revealed in the chromosphere spectrum. Amongst other things, it must then appear

TABLE VIII

RESIDUALS FOR LINES TO THE VIOLET OF MUCH STRONGER LINES SHOWING LARGE ANOMALOUS DISPERSION

Influencing Line	Element	Intensity	Distance 0–1 A	Residual	Distance 1–2 A	Residual	Distance 2–3 A	Residual	Distance 3–5 A	Residual
3933.825	Ca	1000	....	....	1.040	−0.006	2.556	−0.008	3.375	−0.001
					1.664	− .010	....	....	3.803	− .004
									4.328	− .004
									4.462	− .004
									4.565	− .004
3944.100	Al	15	0.439	+0.001						
			.671	+ .002						
			.838	+ .016						
			.922	+ .012						
3961.674	Al	20	.393	− .001	1.252	+ .002				
3968.625	Ca	700	....	....	1.055	− .008	2.413	− .006	3.962	− .003
					1.847	− .004	2.556	− .005	4.209	− .002
					1.978	− .008	2.970	−0.003	4.794	+0.002
4077.885	Sr	8	.926	.000	1.093	− .003				
					1.241	− .001				
					1.510	− .004				
					1.784	− .001				
4226.904	Ca	20	.320	− .005	1.030	− .003				
			0.788	−0.004	1.285	−0.003				
Weighted mean				+0.0006		−0.0038		−0.0054		−0.0023
No. of lines				8		12		4		8
No. of measures				51		67		25		44

TABLE IX

RESIDUALS FOR LINES TO THE RED OF MUCH STRONGER LINES SHOWING ANOMALOUS DISPERSION

Influencing Line	Element	Intensity	Distance 0–1 A	Residual	Distance 1–2 A	Residual	Distance 2–3 A	Residual	Distance 3–5 A	Residual
3933.825	Ca	1000	....	....	1.638	−0.010	2.140	−0.002	3.654	−0.002
							2.206	− .009	4.335	− .005
									4.614	− .004
									4.727	− .001
3944.160	Al	15	0.724	+0.002	1.100	+ .002				
			.873	+ .001	1.198	+ .008				
			.968	+ .002	1.313	+ .001				
					1.833	− .001				
3961.674	Al	20	.815	− .001	1.321	+ .001				
					1.578	− .005				
3968.625	Ca	700	.788	+ .001	1.159	− .002	2.850	−0.004	3.688	− .009
					1.274	− .008	....	....	4.095	.000
					1.794	− .004	....	....	4.431	+0.006
					1.915	− .004				
4077.885	Sr	8	.630	− .001	1.685	− .003				
			.746	+ .004						
4226.904	Ca	20	0.702	−0.004	1.199	− .003				
					1.975	−0.002				
Weighted mean	....	....	....	+0.0003	....	−0.0018	....	−0.0049	....	−0.004
No. of lines	....	....	....	8	....	14	....	3	....	7
No. of measures	....	....	....	62	....	84	....	21	....	37

whether those elements whose lines are most conspicuous in the chromosphere light do actually cause uncommonly great anomalous dispersion—a wide field for experimental research, the exploration of which has only just commenced.[1]

A comparison between Geisler's results and the latest flash spectrum data of Mitchell shows, however, that lines showing very small anomalous dispersion in the laboratory are often conspicuous in the chromospheric spectrum, while lines exhibiting it to a high degree in the laboratory may fail in conspicuousness. The lines of the violet magnesium triplet at λ 3833, intensities 10, 15, and 25, are assigned heights of 6000–7000 km, while neighboring lines of mean intensity 5 show a mean height of 600 km. Though the magnesium lines show weak anomalous dispersion and are only four times as strong, they show heights nearly tenfold as great as the comparison lines. The Fe line λ 3860, intensity 20, anomalous dispersion weak, has a height of 6000 km. Comparison lines of mean intensity 6 show a mean height of 800 km. The D lines of sodium show the phenomenon in the laboratory to an enormous degree. Mitchell finds their height to be 1000 km, while neighboring lines of mean intensity 5 upon the same plate are given a mean height of 360 km; so that the D lines, though 5 times as strong, produce arcs only about 3 times as long as the comparison lines. Of the calcium lines, λ 4226.9 shows anomalous dispersion to the highest degree; it is given a height of 5000 km against 14,000 km for the H and K lines, which show less anomalous dispersion. The two factors that appear to be more consistently effective than anomalous dispersion in producing conspicuous chromospheric reversals of the Fraunhofer lines seem to be great normal intensity and enhancement under reduced pressure.

When Mr. Adams made a direct and apparently rational comparison between laboratory results and displacements at the limb and could find no relation between them, it was answered that such a simple comparison could not serve the purpose, because a peculiar feature of the explanation from the point of view of anomalous dispersion is that both very strong and very weak anomalous dispersion make the displacements small, whereas intermediate values give larger displacements. It is of interest to apply this new cri-

[1] *Astrophysical Journal*, 12, 194–195, 1900.

terion to the displacements found by Mr. Adams. The results based upon the same lines that Mr. Adams used are as follows. The figures in parentheses show the number of lines involved in the comparison:

	Anomalous Dispersion			
	Strong	Moderate	Weak	Very Weak
Displacements....	+0.006 A (21)	0.002 A (2)	0.0044 A (13)	0.0061 A (30)

The contradiction between theory and observation appears quite evident.

As the displacements at the edge of the penumbrae of eccentrically located sun-spots were considered by Professor Julius to be due to anomalous dispersion, it seemed of interest to apply the foregoing criterion to these displacements. The results were unfavorable to the dispersion theory as I apprehended it. It is now shown by Professor Julius that the criterion did not fit this case, but that the test of mutual influence is to apply. In my list of 506 lines there are 131 lines in the near neighborhood of stronger lines, that is, under the influence of these lines, but they show no systematic differences from lines not so situated.

It is worthy of note that Professor Julius takes no account of laboratory results when considering center and limb displacements; but to prove that very strong and very weak anomalous dispersion make the displacements small and that intermediate values give larger displacements, he classifies the lines simply according to line-intensity, irrespective of their known anomalous dispersion. This appears to assume that anomalous dispersion is proportional to line intensity. Likewise, there is no attempt to correlate the effects of mutual influence with what is known of the power of the influencing lines to produce anomalous dispersion phenomena. It seems again to be assumed that all lines of the same intensity are equally effective. The behavior of the great winged lines of magnesium and of many of the strongest lines of iron whose cores are bounded by broad shadings seems to contradict the assumption. These wings

or shadings are explained as "dispersion bands" and it seems probable that their breadth and intensity would bear a direct relation to the power of the lines to produce anomalous dispersion effects; but the lines referred to show weak or very weak anomalous dispersion. The D lines of sodium showing anomalous dispersion out of all proportion to other lines are not bordered by shadings that are proportionately conspicuous or that are comparable with those bordering the H and K lines of calcium. The extent and intensity of the wings appear to depend upon the strength of a line and upon the form of its emission-curve rather than upon the amount of its anomalous dispersion. The disappearance of the wings at the limb, a very striking phenomenon, has as yet received no explanation from the point of view of anomalous dispersion.

In Professor Julius' last paper[1] he seems to have freed the anomalous dispersion theory from the ordinary canons for correlating laboratory and solar observations on the ground that the relations of anomalous dispersion are peculiar to itself, so that it becomes increasingly difficult to correlate the two classes of phenomena. Taken in connection with the great flexibility of the theory this renders it difficult of proof or disproof by observations.

THE RELATIVE LEVEL OF THE ELEMENTS

Professor Julius says: "St. John attempts to corroborate his intensity-and-level hypothesis by considering the atomic weight of the elements in connection with the displacements of their lines in the spot spectrum. We may doubt whether the data suffice for the purpose."

He refers to a statement of mine, where I say: "But on the chart it will be noticed that the lines of the heavy elements, such as barium, lanthanum, neodymium, cadmium, cerium, lead, and ytterbium, originate at lower levels than the lines of like intensity of iron." I regret that I made the mistake of writing neodymium instead of niobium, and I am glad to have the error called to my attention. On the chart the lines of neodymium are not below those of iron of the same intensity.

[1] *Astrophysical Journal*, **40**, 19–20, 1914.

Professor Julius says further: "But if we refer to Table I of the first paper we find that the evidence is not very strong." As Professor Julius has raised the question, it may be well to present the facts relating to the heavy elements in some detail.

In comparing the displacements of the lines of the heavy elements with those of iron, Professor Julius falls again into the error of using displacements of the iron lines deduced from the six separated regions, though 19 of the 21 lines of the heavy metals are in the violet, for which region the generalized iron scale is slightly high. The correct procedure is, of course, to compare these displacements with those for iron in the same spectral region and measured upon the same or interconnected plates, as in Table X.

TABLE X

DISPLACEMENTS OF THE HEAVY ELEMENTS COMPARED WITH IRON

Element	Intensity	λ	Observed	Mean for Fe	Residuals	Residuals by Elements
Ba.....	2	4130	0.027	0.020	+0.007	+0.005
	5	5853	.029	.026	+ .003	
Ce......	1	4111	.028	.022	+ .006	+ .002
	3	4129	.022	.014	+ .008	
Fe, Ce..	1	4137	.014	.022	− .008	
Cd.....	3	4678	.038	.033	+ .005	+ .005
La......	2	3628	.019	.018	+ .001	+ .002
	1	3694	.027	.022	+ .005	
	1	3995	.014	.022	− .008	
	1	4086	.026	.022	+ .004	
	2	4123	.023	.020	+ .003	
	2	4196	.024	.020	+ .004	
	4	4204	.020	.014	+ .006	
	2	4287	.019	.020	− .001	
	1	4333	.026	.022	+ .004	
Nd?....	2	3994	.020	.017	+ .003	.000
	1	4109	.016	.022	− .006	
	1	4116	.025	.022	+ .003	
Nb.....	1	4232	.030	.020	+ .010	+ .010
Pb.....	1	4387	.026	.020	+ .006	+ .006
Yt......	3	3694	0.020	0.014	+0.006	+0.006

Of the 21 lines 3 show large negative residuals: λ 3995, a nebulous and difficult line of intensity 1 belonging to lanthanum; λ 4137,

a line attributed to cerium, where the negative evidence seems to Professor Julius to deserve being italicized; and a line of neodymium. In regard to the cerium line, a reference to Rowland's Table would have shown that it may as well be called an iron as a cerium line. It was placed upon the observing list through an inadvertence and has not been treated as a cerium line in any discussion. I regret that the full Rowland identification was omitted from the table and that the cerium line λ 4111 appears by a typographical error under the cobalt symbol. The La line λ 3995 is between lines of intensities 3 and 5. Professor Julius has evidently judged that its large negative residual is due to its being on the violet side of the line of intensity 3, but the line λ 4137 is less than a fourth of an angstrom to the red of a stronger line and therefore according to the anomalous dispersion theory should give a positive residual. The residual is large and negative. As to the neodymium lines, it is well known that their identification is only suggested and rests upon no accepted evidence.

The emphasis that Professor Julius places upon these negative residuals leads one to remark that there are two distinct plans for an investigation such as I undertook. One can select a few lines well adapted to measurement and, by concentrating upon them, results of very high accuracy may be obtained; but in that case everything depends upon the selection of the lines. On the other hand, the investigation may be extended, as in this instance, to a wide range of elements and lines. For elements represented by many lines a selection was possible, but for the heavy elements all lines were measured. In such an extended investigation dependence must be placed upon means obtained by statistical treatment, and these in the case of the heavy elements shows such a preponderance of positive residuals that the general result appears to be established by the observations. Professor Julius raises the question of zircon. The measurement of the weak zircon lines in the solar spectrum is particularly difficult. The facts are given in Table XI.

The situation is not quite so bad as Professor Julius puts it. He implies that six of seven lines give decidedly negative residuals when compared with iron. But the evidence given by the mean of the first five in the list is quite indecisive. Two of the remaining three

are close to the red side of stronger lines and should, according to the dispersion theory, give positive residuals; these residuals are, however, −0.004 A and −0.005 A. These two lines, as well as λ 4137, must then, from the point of view of anomalous dispersion, be affected by errors of observation. The remaining is represented in neither the arc nor spark spectrum of zircon.[1] I regret that by a typographical error the line λ 4277 appears in the table as a Cr line.

TABLE XI

COMPARATIVE DISPLACEMENTS OF THE ZIRCON AND IRON LINES

λ	Intensity	Observed	Mean for Fe	Residual
4149	2	0.016	0.020	−0.004
4183	1	.024	.022	+ .002
4273	2	.021	.020	+ .001
4277	0	.026	.024	+ .002
4294	2	.018	.020	− .002
4304	0	.020	.024	− .004
4359	0	.019	.024	− .005
4374	0	0.015	0.024	−0.009

In this connection it is of interest to consider an element whose level is higher than iron. When the displacements of the titanium lines are compared with those of iron of the same intensity and spectral region the result is as in Table XII.

TABLE XII

DISPLACEMENTS OF TITANIUM COMPARED WITH THOSE OF IRON

Intensity	No. of Lines	Mean Ti-Fe
0	6	−0.0020 A
1	7	− .0024
2	18	− .0028
3	10	− .0026
4	6	−0.0025
	47	−0.0026 A

Professor Julius adds: "If, however, the accuracy attained would permit of regarding such deviations as genuine, the interpretation of the displacements on the basis of the Doppler effect

[1] Kayser, *Handbuch der Spectroscopie*, 6, 864, 1912.

would be condemned. One could not reasonably admit the various absorption centers present in a gas-current at a certain level to have different proper velocities of outflow from the spot vortex."[1]

It was precisely because the deviations were considered to be genuine and because one could not reasonably admit that the absorption centers present in a gas-current at a certain level can have different velocities, that one was led to the assumption that they are at levels differing with their velocities. It is to be observed that the deviations between the displacements of the lines of these elements and of iron are of the same order as those between iron lines of neighboring intensities which Professor Julius considers to be genuine and explicable from the point of view of his theory.

In saying that the displacements of the Fe lines of intensity 4, for example, are in magnitude between those for lines of intensities 3 and 5, it is meant that, when the data are sufficient, the mean displacement for lines of intensity 4 is less than that for lines of intensity 3 and more than that for lines of intensity 5; not that the statement is true for every line of the respective intensities, otherwise there would be no room for errors of measurement and no need for the tedious duplication of observations by extending them to ever-larger numbers of lines. In an exactly similar way and to the same degree, one is justified in saying that the displacements of the lines of the heavy elements are, as a class, greater than for the iron lines of corresponding intensities. There are several grounds for expecting deviations from the mean: (1) errors of measurement of weak lines which are inherently great are somewhat above normal because in general the intensity of development of the plates was intended for the measurement of lines of medium intensities; (2) errors in the Rowland intensities, which are quite large for the weaker lines, in which case the individual variations are so pronounced that the results for a single line must be accepted with caution unless its intensity is verified; (3) there is always the possibility of the line in question being an undetected blend, especially in the ultra-violet region where the lines are so numerous; (4) there are apparently differences characteristic of the different

[1] *Astrophysical Journal*, **40**, 7, 1914.

groups of lines of a given element.[1] It is first necessary, however, to establish the broader outlines of a general truth, if it exists, then later the individual variations may be used to push investigation a step farther.

GENERAL DISPLACEMENTS OF FRAUNHOFER LINES

Another deduction from the dispersion theory is said by Professor Julius to be proved by the center and limb displacements observed by Adams. These displacements, according to that theory, are a more pronounced effect of the general shifting of the Fraunhofer lines to the red, which is ascribed to their asymmetry. Both phenomena, the general shift and the center and limb effect, are similarly produced, are subject to the same laws, and may be judged by the same criterion. In the case of the center and limb observations the displacements are small for lines of weak intensity, increase to a maximum for lines of intermediate intensity, then decrease for lines of great intensity. Professor Julius says: "This is exactly what our theory requires. . . . . Lines of moderate intensity should show the largest displacements, as they really do."[2]

It is interesting to compare the above definite statement with the results obtained from observations of general shift. The Fe lines of the groups *a*, *b*, and *c*4 are the best lines in the iron spectrum for standards, their wave-lengths, under constant pressure, are independent of arc conditions, and the lines are of excellent quality both in the arc and in the solar spectrum. An extended series of observations on sun-arc displacements is a part of the Mount Wilson program. Some preliminary results are now being prepared for publication and their general discussion will appear later. In the list are 105 lines of groups *a*, *b*, and *c*4. A synopsis of the means taken by intensities is given in Table XIII.

For comparison the limb-center shifts are included, and also the sun-arc results of Evershed. The result based upon these lines for which sun-arc displacements can be obtained with high precision is at variance with the deduction from the anomalous dispersion

[1] *Mt. Wilson Contr.*, No. 74; *Astrophysical Journal*, **38**, 352, 1913.

[2] *Observatory*, **37**, 256, 1914.

theory. For lines of moderate intensity 5 the displacement is a minimum instead of a maximum. The march of the phenomenon for the iron lines shown by Fig. 2 appears not to be accidental, for the lines of group *a* taken separately, the two sections of the *b* lines in the violet and red respectively, and the lines of the same groups in the list published by Evershed[1] show a similar march of displacement with intensity.

TABLE XIII

SUN-ARC DISPLACEMENTS—IRON LINES

	Intensity							
	2	3	4	5	6	7	8	10–15
No. of lines	9	22	29	16	13	5	10	3
Sun-arc...	+0.0047	+0.0038	+0.0030	+0.0020	+0.0042	+0.0058	+0.0090	+0.0110
Evershed..	+ .0083	+ .0047	+ .006	+ .0055	+ .0077	+ .0135	+ .0134	+ .015
Limb-center...	+0.0066	+0.0068	+0.0071	+0.0088	+0.0083	+0.0088	+0.0079	+0.0041

There are many lines showing negative shifts for the sun-arc comparison. The evidence that these displacements to shorter wave-length are real will be found in the paper to which reference is made above. Shifts in the solar atmosphere to shorter wave-lengths appear to be unaccounted for by the anomalous dispersion theory.

A further and very serious difficulty for the theory appears in classifying the lines into groups by sun-arc displacements, that is, in putting into each category lines showing similar behavior in the sun, as the lines fall into the same groups as when classified by pressure-shift in the laboratory. The hallmark of pressure-shift is evident, but discussion is reserved for the paper on "Pressures in the Solar Atmosphere" now in preparation. It is of interest here only from its bearing upon the deduction from the anomalous dispersion theory.

In reference to the limb-center displacements Professor Julius remarks: "Adams himself considers pressure as the effective agent

[1] *Kodaikanal Observatory Bulletin*, No. 36, 1913.

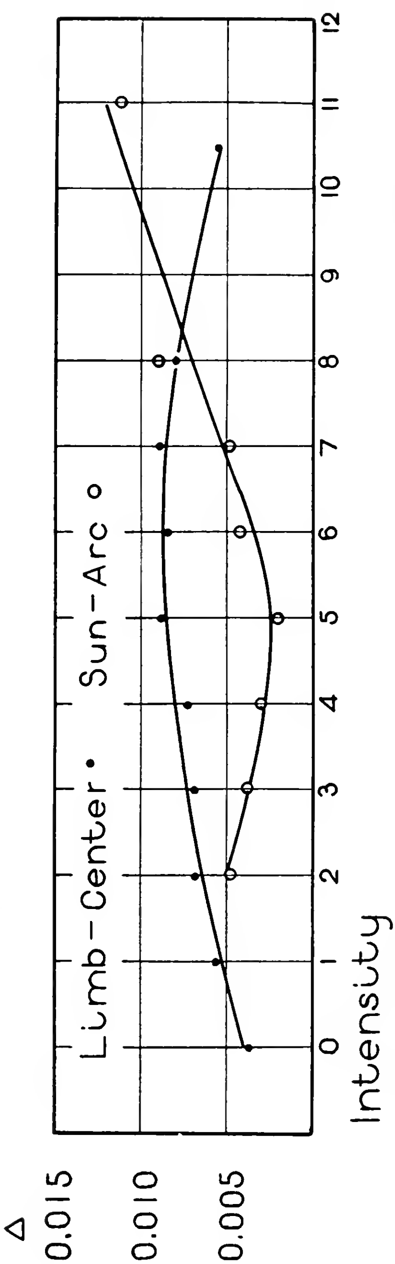


FIG. 2.—Limb-center displacements are from the observations of Adams. Sun-arc displacements are of Fe lines of groups *a*, *b*, *c*4.

in producing these displacements; it therefore did not occur to him to classify the shifts according to line intensity."[1]

It would more accurately represent Mr. Adams' attitude to say that he did not classify the shifts according to line intensity because he recognized that the characteristic behavior of the elements and classes of lines would be concealed rather than revealed by the treatment of heterogeneous data *en masse*. It seems to be implied that Mr. Adams considered pressure the only effective agent concerned in the center and limb displacements. Such an inference is hardly consonant with Mr. Adams' discussion of the question of the heavy elements and the enhancement of lines, and his treatment of scattering, motion, and level. In respect to the latter he begins a discussion with the expression: "Since the matter of level appears to be the most significant factor in determining the amount of the displacement for any given line . . . . ;[2] and it was at his suggestion that I took up the question of level and center-limb displacements in my second paper on "Radial Motion in Sun-Spots."[3]

ERRORS OF OBSERVATION

Professor Julius says: "A very marked fact not explained by St. John's theory, viz., the large deviation of individual displacements from the means for each intensity class and spectral region, is shown to be in harmony with our interpretation on the basis of anomalous dispersion."[4]

There are 131 lines in the lists of those to the violet or red of stronger lines. In such cases the large deviations explained only by the dispersion theory should be in evidence. The mean deviation for these lines without regard to sign is 0.003 A, which compares favorably with the precision obtainable in other solar spectrum measurement where the difficulties of measurement are of the same order. The mean of the 25 largest deviations of this class is 0.007 A, while for 25 lines not under the influence of stronger lines it is 0.009 A.

[1] *Astrophysical Journal*, **40**, 27, 1914.

[2] *Mt. Wilson Contr.*, No. 43, p. 26; *Astrophysical Journal*, **31**, 55, 1910.

[3] *Mt. Wilson Contr.*, No. 74, p. 23; *Astrophysical Journal*, **38**, 341, 1913.

[4] *Astrophysical Journal*, **40**, 25, 1914.

As to the lack of proportionality between displacements and wave-lengths, Professor Julius says: "One cannot admit such fluctuations to be entirely accidental or due to observational errors. The important retrograde differences between the values for the mean λ 4732 and mean λ 5235, e.g., far exceeds the mean errors of the result of 76 and 86 observations, and must be genuine."[1]

On this point I am unable to make so definite a statement. I can only say I was impressed by the great difference in absolute values obtained from exposures taken in immediate succession even upon the same plate and in the same region. The area of maximum displacement is very narrowly localized at the edge of the penumbra, and unless the seeing is exceedingly fine the slit cannot be placed on the exact point; and when, as was sometimes the case, observations had to be made under conditions of poor seeing when the edge of the penumbra nearly disappeared, still greater variations were found. Although Professor Julius considers the high values of the displacements in the region λ 4634–λ 4829 to represent a genuine divergence, he has nevertheless treated them as accidental in determining his normal displacements by a smoothing-out process. Consequently the normals are high for the violet and green regions and low for the region of mean λ 4732. In selecting the six spectral regions there was no thought of using them for determining the relation between displacement and wave-length. It was plain that an impracticable number of observations for each region would be required to eliminate the accidental differences between the regions. When, however, the results were finally assembled, the variation of displacement with wave-length was so evident, in spite of the deviations for the separate regions, which my experience told me might be due to observational conditions, that it seemed a fair assumption to refer these displacements to the Doppler effect and to leave final appeal to observation until the approaching spot maximum.

In considering the data in my original list of displacements, a clear distinction should be kept in mind between errors of measurement and errors of observation. In any one of the six spectral regions the relative displacements of the different lines are subject

[1] *Ibid.*, **40**, 24, 1914.

only to errors of measurement, while the relative values for the means of the segregated regions are affected by the large variations in absolute displacements from plate to plate inherent in the difficulties of the observations.

SOME OUTSTANDING DIFFICULTIES

1. The regular progression of the heights given by flash spectrum lines with solar intensities leads directly to the same relative levels as those deduced from the displacements in the penumbrae of spots. The explanation on the theory of anomalous dispersion would seem to require anomalous dispersion to be directly proportional to the intensities of lines, and the arcs given by flash lines to be directly proportional to the anomalous dispersion of the lines, neither of which appears to be in harmony with observation.

The 346 Fe lines, unenhanced and identified only with iron, in Mitchell's Table I, show the following results:

	No. of Lines									
	4	19	30	55	72	49	40	28	24	25
Solar intensities......	00	0	1	2	3	4	5	6	7–8–9	10–40
Heights in km.......	275	279	288	344	369	397	425	488	590	806

2. The regular change in the intensities in the flash lines relative to the intensities of the corresponding solar lines is a marked phenomenon and is not an obvious deduction from the anomalous dispersion theory. There are in Mitchell's Table I, 1181 unenhanced lines of intensity 6 or less assigned to single elements. The differences, flash—solar intensity, expressed in intensity intervals, are as follows:

	No. of Lines									
	18	69	164	166	189	185	166	109	71	44
Solar intensity	0000	000	00	0	1	2	3	4	5	6
Flash—solar.........	+3.4	+2.3	+1.4	+0.6	+0.1	−0.7	−1.1	−2.1	−2.7	−3.2

3. Some two years ago I published observations showing displacements when the slit of the spectrograph is perpendicular to the

radius of the solar disk passing through the center of the umbra.[1] It is implied by Professor Julius that such displacements are only occasional and occur when the region of minimum density has not a symmetrical shape.[2] Of the spots examined at the time of publication, 70 per cent showed such displacements and practically all spots examined since then by more refined methods of observation have shown these displacements. They occur and persist for weeks in regular and symmetrical spots, so that one can hardly admit that "there is no difficulty in accounting for the occasional displacements in question on the basis of unequal refraction at opposite edges of the spots." It may be possible to imagine a density distribution capable of producing the effect "since almost any peculiarity in the appearance of spectral lines may be explained by anomalous dispersion, if only we are at liberty to assume the required density distribution,"[3] but that such an artificial condition characterizes a regular spot during at least the greater part of its life seems improbable, and the mind reverts to the obvious explanation based on vortex motion.

4. There are some lines displaced in the opposite direction in the penumbrae of spots, but their small number does not lessen the difficulty for the dispersion theory. Not only are they among the most important chromospheric lines, but they often show displacements that are pronounced and obvious without measurement, they appear in every observation, and indicate a comparatively stable condition during the life of a spot. Up to the present the anomalous dispersion theory has been unable to suggest an explanation, and the Doppler effect due to the inflow of the upper chromospheric vapors is as yet the only one proposed.

5. No explanation is furnished by the dispersion theory of the differences characteristic of the elements such as those shown by the displacements of the lines of iron, titanium, and the heavy elements when lines of the same region and intensity are compared.

EFFECTIVE LEVELS

The idea of levels has been employed in all spectroheliographic work, particularly by Hale and Deslandres, and has been previously

[1] *Mt. Wilson Contr.*, No. 54, p. 20; *Astrophysical Journal*, **34**, 76, 1911.

[2] *Ibid.*, **40**, 29, 1914.

[3] *Ibid.*, **25**, 111, 1907.

discussed by Abbot[1] and by the writer.[2] It is a familiar observation that the different arc lines of iron, for example, are not produced with equal relative intensity in all parts of the arc. Some appear only at the poles, others only in the core, while others are characteristic of the flame of the arc. For these three classes of lines the effective centers of radiation are not uniformly distributed throughout the mass of radiating vapor. If such a body of vapor were backed by a suitable continuous spectrum, the absorption lines would be referable to different portions of the arc. Suppose, for example, that the core of the arc could be put into rotation with a velocity greatly differing from that of the outer layers. Such a difference in motion could conceivably be detected by the inclination of the spectrum lines if the slit of the spectrograph were normal to the axis of the arc, since different portions of the arc are effective in the production of the classes of lines considered. Again let us consider systems of electrons emitting a number of lines of very different intensities in a mass of vapor of solar proportions with a similar distribution of temperature and density. For the strongest lines the absorption coefficient is the greatest and there will be a spherical core from which no light of these wave-lengths reaches the surface, that is, the emergent light of these wave-lengths comes from a spherical shell. The total radiation is an integrated effect and its center of gravity locates the effective radius of the shell or the effective layer. From the levels of the shorter radii of the shell the light emitted at the outer surface is small owing to the absorption; from the levels of the longer radii it is again small owing to the lower temperature; it is evident that the really effective level lies between these extremes. The lines will appear dark, as Abbot suggests, in contrast to the light that is not selectively absorbed, since such radiation comes from lower and hence hotter levels. If attention be directed to the weakest lines of the system, it is seen that light of these wave-lengths will reach the surface from a greater depth owing to the smaller coefficient of absorption, that low levels will be more effective and the higher

[1] *The Sun*, pp. 97 and 251.

[2] *Mt. Wilson Contr.*, No. 74, p. 5; *Astrophysical Journal*, **38**, 345, 1913; *Mt. Wilson Contr.*, No. 88, p. 18; *Astrophysical Journal*, **40**, 373, 1914.

levels less effective for the weakest than for the strongest lines, so that the center of gravity of the integrated effect is lower, that is, the effective level is lower for the weakest lines than for the strongest lines. From this point of view it is evident that the existence of tangential velocities varying with the depth could be detected spectroscopically. That these lines of different intensities may belong to a series does not seem to require modification of the discussion.

Professor Julius urges against this point of view that in the laboratory a gas such as NO_2 shows at the same time strong and weak lines. It is also true that the calcium spark gives ordinarily λ 4226.9, H, K, and many weaker lines, but de Gramont[1] has shown that K is the ultimate line, the last to disappear when the quantity of the element tends toward zero. If the quantity be sufficient to show K only, it is evident that the corresponding absorption spectrum would show K only, and that with increasing quantities of Ca vapor H, λ 4226.9, and other lines would appear in succession. It seems a clear deduction that the upper portion of the Ca envelope of the sun would be the source of the K_3 line and that a greater depth of vapor would be necessary to produce the line λ 4226.9, or the center of gravity of its effective layer would be lower. In the laboratory experiment with NO_2 the range of intensity of the absorption lines depends upon the quantity of vapor in an apparently similar way.

SUMMARY

1. In the lists published by Professor Julius there are 43 lines to the violet and 39 lines to the red of stronger lines. Among the 506 lines of my original list there are 24 other lines to the violet and 25 to the red of stronger lines within half an angstrom of stronger lines. Using the Julius normals the mean residual for the additional lines to the violet is +0.0023 A, and for those to the red −0.0034 A, results opposite to those given by the lines selected by him, and at variance with the theory.

2. In deducing the normal displacements for a given intensity and region from those for the separate regions, one is dealing with non-homogeneous series of observations. The use of these normals

[1] *Comptes rendus*, **159**, 5–12, 1914.

introduces residuals that are systematically negative for lines in Professor Julius' lists which are to the violet of stronger ones, because such lines are all in the violet and green regions, for which the normals are too large. The apparent positive residual for lines to the red of stronger ones depends upon 7 lines in the blue series for which the normals are 0.009 A less than the mean for all lines of the same intensity and region.

3. Using as standard displacements in any homogeneous series the means from all lines of a given element and intensity in that region, the resulting residual for the 67 lines to the violet is −0.0003 A and for the 64 lines to the red −0.0004 A. For the 131 lines the sum of the favorable residuals is 0.212 A, of the unfavorable residuals 0.218 A. Tested, then, by standards deduced from the homogeneous group of observations to which they are to be applied, the lines in the near neighborhood of stronger lines show no systematic differences from lines not so situated.

4. Influencing lines showing very strong anomalous dispersion exert no greater effect upon neighboring lines than those showing very weak anomalous dispersion.

5. New measurements of weak lines in the broad shadings of the strongest lines in the solar spectrum show no systematic differences for lines near them nor any systematic progression in the displacements as the strong lines are approached.

6. Criteria given by Professor Julius relating anomalous dispersion to the chromospheric and limb spectra are applied with results unfavorable to the theory, and consideration is given to the increasing indefiniteness of the correlation between laboratory results on anomalous dispersion and solar observation.

7. Professor Julius compared the displacements of the lines of the heavy elements with the standard displacements of the iron scale, which are high for the violet region, and by this procedure reduced the positive residuals. The displacements of the 21 lines of the heavy metals exceed those for the same intensities of iron on the average by +0.003 A when comparison is made with iron lines upon the same plates.

8. The general displacements of the Fraunhofer lines to the red are a minimum for lines of medium intensities, a result opposite to

that required by the anomalous dispersion theory; and there are, moreover, many lines displaced to shorter wave-length, a phenomenon yet unaccounted for by the theory.

9. Classified by their displacements in the solar atmosphere the iron lines fall into the same classes as when classified by pressure-shift, a result apparently not to be explained by anomalous dispersion.

10. A consideration of errors shows that for a given region they are not abnormal for weak lines near stronger ones, and that the departures from regularity, when unconnected regions are compared, may be referred to the difficult observing conditions.

11. The general conclusion from this review of solar observations is that the deductions from the anomalous dispersion theory which are susceptible of definite and quantitative tests are not supported by the observational data, and that observations are outstanding which have not yet been explained by the theory.

Mount Wilson Solar Observatory
October 22, 1914

Minor Contributions and Notes

ON THE SPECTRUM OF YTTRIUM

In a preceding article[1] I have investigated briefly the spectrum of yttrium with regard to the arrangement of the strongest lines in groups with constant differences between their wave-numbers. In that work three constant differences were discovered with the values 205.00, 84.67, and 3241.48, respectively. The first of these occurs in the case of seven pairs of strong lines; the second in three. The third difference, which occurs in two pairs only, should, as I afterward found, be replaced by 143.84. The four lines which form the two pairs should be interchanged.

Since then I have made a more careful investigation of the same spectrum, the results of which are given in the following. The measurements of the wave-lengths, taken from Kayser, are the most exact, and reach from λ 6701 to λ 2227. Some lines, however, not being given by Kayser, but certainly existing, have also been included, for instance λ 4236.10. Its intensity, according to Exner and Haschek, is 10, while Eberhard calls it 6.

The above-mentioned difference 205.00 belongs to a group of 4 lines. Designating the wave-numbers of the first line (with the greatest wave-length) in each group by A, we get for the wave-numbers B, C, and D of the other lines in the same group:

$$B=A+1846.91$$
$$C=A+2251.69$$
$$D=A+2456.65$$

The differences between the lines in each group are in the mean 1846.91, 404.78, and 204.96, respectively.

I have brought together all the lines belonging to this group in Table I, which is arranged in the following manner. In the columns, called A, B, C, and D, are given the wave-numbers (in the calculation of which but two decimals have been used in the wave-length); in the columns I, Δ_1, Δ_2, and Δ_3 are given the intensities

[1] *Beiträge zur Kenntnis der Linienspectren.* Diss. Lund, 1914; *Annalen der Physik.*, **45**, 429, 1914.

of the lines, according to Exner and Haschek, and the differences of their wave-numbers.

TABLE I

I	A	$\Delta_1=1846.91$	I	$B=A+1846.91$	$\Delta_2=404.78$	I	$C=A+2251.69$	$\Delta_3=204.96$	I	$D=A+2456.65$
1	15633.33	1846.74	4	17480.07	405.28	1	17885.35	205.13	10	18090.48
10	16069.96	1847.01	1	17916.97	....	...	....	....	...	....
...	....	....	...	....	....	1*	16439.80	204.87	2	16644.67
...	....	....	2	17006.16	404.62	1*	17410.78	....	...	....
...	....	....	1	17420.33	....	...	....	(609.93)	3	18030.26
...	....	....	...	....	....	1†	17618.50	204.96	1	17823.46
2	19243.39	1846.54	4	21089.93	404.76	2	21494.69	....	...	....
10	19655.63	(2252.19)	...	....	....	2	21907.82	205.11	2	22112.93
1	20207.17	1846.95	2	22054.12	....	...	....	....	...	....
1	20344.89	1847.05	8	22191.94	....	...	....	(609.70)	2	22801.64
...	....	....	...	....	....	1	20357.82	204.85	2	20562.17
...	....	....	10	20406.91	404.79	3	20811.70	....	...	....
2	20484.96	(2251.61)	...	....	....	10	22736.57	205.00	8	22941.57
4	21356.11	1846.93	20	23203.04	404.97	10	23608.01	204.69	3	23812.70
...	....	....	4	21715.62	....	...	....	(609.89)	2	22325.51
...	....	....	2	21732.14	....	...	....	(609.74)	4	22341.88
...	....	....	...	....	....	4	22283.23	204.80	4	22488.03
...	....	....	1	22557.32	....	...	....	(609.75)	2	23167.07
...	....	....	3	22753.95	404.65	1*	23158.60	....	...	....
50	22856.57	1846.99	8	24703.56	404.71	20	25108.27	204.98	20	25313.25
15	23936.73	1846.97	2	25783.70	404.52	5	26188.22	205.08	20	26393.30
5	24241.95	1847.21	10	26089.16	404.49	20	26493.65	....	...	....
3	25305.30	1846.55	1	27151.85	405.09	10	27556.94	204.87	10	27761.81
3	25440.11	1846.95	20	27287.06	404.64	20	27691.70	204.95	10	27896.65
...	....	....	...	....	....	5‡	26478.00	205.03	5	26683.03
...	....	....	...	....	....	2	26846.22	204.78	2	27051.00
...	....	....	20	27770.99	404.77	10	28175.76	....	...	....
3‡	27871.53	1846.86	3	29718.39	....	...	....	....	...	....
1†	28630.98	1846.97	3	30477.95	....	...	....	....	...	....
5	28994.25	1847.00	20	30841.25	404.94	10	31246.19	204.90	5	31451.09
3	28834.81	[2251.88]	...	....	....	20	31086.69	204.97	10	31291.66
20	30047.99	1846.98	4	31894.97	404.77	8	32299.74	....	...	....
...	....	....	1*	33219.72	404.58	1	33624.30	205.20	1	33829.50
...	....	....	1†	35498.00	404.90	1	35902.90	....	...	....
...	....	....	...	....	....	1	43903.17	205.06	1	44108.23
...	....	....	...	....	....	...	....	....	...	....
...	....	....	...	....	....	...	....	....	...	....
...	....	....	...	....	....	...	....	....	...	....

* Seen by Kayser only. † Seen by Exner and Haschek only. ‡ Not seen by Kayser.

All places are not occupied by lines in Table I. In some cases the gaps may be caused by lines unobserved on account of their small intensities. In other cases this is not to be assumed, for the

remaining lines of the same row have too great intensity and a gap here must depend upon unknown causes.

The lines, the wave-numbers of which have the differences 143.84 and 84.93, seem to be isolated pairs in the spectrum and I have not been able to find any corresponding lines. The pairs with these two differences are given in Tables II and III. The

TABLE II

I	*A*	Δ=143.84	*I*	*B*
1*	16257.68	143.83	1*	16401.51
3	20747.49	143.51	3	20891.00
8	18148.42	144.25	10	18292.67
2	20492.51	143.66	8	20636.17
5	21003.24	144.17	5	21147.41
3	21322.24	143.99	8	21466.23
10	21390.23	143.58	10	21533.81
1*	21610.45	143.96	6	21754.41
1	21807.82	143.72	3r	21951.54
2	22154.48	143.95	2	22298.43
3	22351.01	143.69	3	22494.70
3	22503.11	144.12	2	22647.23
1*	22759.39	143.82	4	22903.21
2†	28314.09	143.67	2†	28457.76
1	32786.68	143.69	2	32930.37
1	44016.99	143.84	2	44160.83

*Seen by Kayser only. †Seen by Exner and Haschek only.

TABLE III

I	*A*	Δ=84.93	*I*	*B*
3	15119.46	84.81	1	15204.27
10	17658.01	85.17	1*	17743.18
1*	17675.71	85.17	8	17760.88
3	17959.87	84.64	2	18044.51
8	20576.00	84.94	10	20660.94
4	22789.90	84.92	1	22874.82
2	23303.39	84.86	1	23388.25
10	23522.00	84.62	10†	23606.62
20	24136.98	85.07	30	24222.05
1*	24416.33	85.13	3	24501.46
10	28602.23	84.85	5	28687.08

*Seen by Kayser only. †Not seen by Kayser.

whole number of lines examined amounts to about 600. Of these, 146 occur in the tables above, and among them most all the strong

lines in the spectrum. It is very possible that more groups of lines can be obtained by further investigation.

EMIL PAULSON

KÅGERÖD
August 1914

NOTE ON THE BLUE SPECTRUM OF ARGON

As is well known, the gas of argon possesses two quite different spectra, the red and the blue. Both spectra can be obtained in Geissler tubes under various conditions. As the quantity of electric energy transmitted to every molecule increases, the red spectrum gradually goes over into a mixed one and this at last into the so-called blue spectrum, which has but a few lines in common with the red spectrum.

The red spectrum of argon has already been examined by Rydberg,[1] who has shown that most of the lines for the interval λ 4702 to λ 2967 can be arranged in quadruplets. Afterward I made an investigation of the red and infra-red part of the spectrum,[2] which has established that the same quadruplet occurs here also. Designating the wave-number of the first line of each quadruplet by A, and those of the following by B, C, and D, we may write:

$$\begin{array}{ll} B=A+\ 846.47 & \Delta_1=846.47 \\ C=A+1649.48 & \Delta_2=803.21 \\ D=A+2256.71 & \Delta_3=607.03 \end{array}$$

Δ_1, Δ_2, and Δ_3 being the succeeding differences between the four lines of the quadruplet.

In order to ascertain whether relations were to be found between the two spectra, I examined all the lines measured by Kayser from λ 5145 to λ 2762. Although I expended a great deal of labor on it, the results of this examination were very insufficient. A group of four lines, however, was discovered, but it does not seem possible

[1] "On the Constitution of the Red Spectrum of Argon," *Astrophysical Journal*, **6**, 338, 1897.

[2] "Zur Kenntnis des roten Argonspektrums," *Physikalische Zeitschrift*, **15**, 831, 1914.

TABLE I

I	A	$\Delta_1=844.49$	I	$B=A+844.49$	$\Delta_2=1611.33$	I	$C=A+2455.82$	$\Delta_3=149.55$	I	$D=A+2605.37$	$\Delta_4=153.97$	I	$E=A+2759.34$
2	19962.37	844.21	6	20806.58	1611.52	2	22418.10	149.27	4	22567.37	153.93	5	22721.30
1	20269.98	844.59	5	21114.57	1611.30	3	22725.87	149.55	4	22875.42	....	...	....
...	....	....	10	22997.90	....	...	....	(1760.91)	2	24758.81	153.99	6	24912.80
9	22592.91	844.50	6	23437.41	1611.46	2	25048.87	149.60	4	25198.47	153.87	4	25352.34
6	23087.47	844.54	1	23932.01	1611.22	3	25543.23	149.66	4	25692.89	....	...	....
5	23650.11	844.47	2	24494.58	1611.10	1	26105.68	149.68	1	26255.36	154.00	2	26409.36
1	24313.64	844.50	1	25158.14	1611.74	1	26769.88						
...	....	....	...	....	....	...	....	(1760.63)	2	27764.82	154.08	4	27918.90
2	25159.46	844.73	1	26004.19	....	...	....	....	...	....	....	...	....
8	25969.20	844.40	9	26813.60	1611.00	1	28424.60	....	...	....	....	...	....

to find any relation between this group and the quadruplet in the red spectrum. The first two differences have nearly the same value, 846.47 and 844.48 respectively, but such a similarity, probably, is quite accidental.

However that may be, there is obviously reason for publishing the results of the research, although they at present cannot give an answer to the question of whether a certain connection exists between the two spectra. With the same notation as above, the group discovered may be represented by the following expressions:

$$
\begin{array}{ll}
B=A+\ \ 844.49 & \Delta_1=\ \ 844.49 \\
C=A+2455.82 & \Delta_2=1611.33 \\
D=A+2605.37 & \Delta_3=\ \ 149.55 \\
E=A+2759.34 & \Delta_4=\ \ 153.97
\end{array}
$$

In Table I some wave-numbers of lines belonging to this group are inserted. The intensities of the lines are indicated by I. In the columns headed A, B, etc., and Δ_1, Δ_2, etc., are given the wave-numbers and their differences.

It will be remarked moreover, that there are a great many pairs in the spectrum, having the differences Δ_1, Δ_2, Δ_3, and Δ_4 and $C-A$, $D-A$, etc. The majority of these pairs surely also belong to the system. All these, however, have been omitted, in order to make the table shorter.

EMIL PAULSON

LUND
December 1914

ON A DEVICE FOR AVOIDING SYSTEMATIC ERROR DEPENDING ON MAGNITUDE IN THE MEASUREMENT OF STELLAR PHOTOGRAPHS

In the wholesale determination of parallax and proper motion by means of photography there is no source of error nearly so troublesome as that depending on magnitude. I even think that but for this one error it would be already possible to free our results completely from systematic error, at least in the averages. I mean that if this error could be removed, there would seem to be no reason why we should not be able—in the average of a sufficient

number of observations or of a sufficient number of stars—to reach almost any desired accuracy. Meanwhile the removal of the error in question has always seemed to me of extraordinary difficulty. Notwithstanding all the thought which has no doubt been devoted to it by different astronomers, myself among the number, no really satisfactory way out of the difficulty has as yet been proposed, and personally I had almost given up the matter in despair when I was struck by the idea which lies at the basis of the method to be described. It seems to hold out good promise of a surprisingly simple and complete solution of the problem. Unfortunately I have not the means myself for thoroughly testing the method, and the first test, kindly made for me at the Potsdam observatory, promising though it appears, cannot be considered as sufficient proof. I must leave it to the interested astronomers to ascertain definitively the practical efficiency of the method. It is evident that our aim will be reached if we succeed in obtaining stellar photographs on which the stars of all different degrees of brightness are represented by perfectly equal images. This can be achieved, at least approximately, in the following way.

a) Let the region of the sky to be investigated be photographed on a plate placed slightly within the principal focus of the telescope. On the developed negative all the stars will be represented by circles having the same diameter. The density of the images will be different, the densest ones of course belonging to the brightest stars.

b) Now let the finished negative—which we will call the screen-plate—be put back in the telescope in its former position, care being taken that the cones of light of the several stars shall meet the plate in exactly the same places as before; and let a second photograph—the main plate—be taken *in focus* (the focal setting being only slightly altered on account of the passage of the light through the plane-parallel screen-plate).

It is at once evident that the light of a *bright* star, before reaching the main plate, will be considerably weakened because it has passed through the dense extra-focal image on the screen-plate. The light of a *faint* star, on the contrary, will have to pass only a faint film-screen and will consequently be but little weakened.

Hence the light of the stars reaching the main plate will be brought nearer to equality by means of the screen-plate. The amount of the change will depend on the time of exposure and possibly some other circumstances. We will of course try to choose these in such a way that the best obtainable approximation to equality of all the images is secured.

The plate courteously taken for me at Potsdam, in the way described, shows the images of all the stars, from α Lyrae down to the stars of the 10th magnitude, nearly equal. Naturally, however, no special arrangements had been made in the plate-holder, and as a consequence the plate is not wholly satisfactory. In an extensive use of the method it will be necessary to take some precautions.

First, in order not to introduce appreciable distortion by the passing of the light through the screen-plate, it seems necessary to use plate glass. There is already some evidence tending to show that, at least in large-scale photographs, sensible error due to distortion by the passage of the light through the glass is not to be feared (e.g., Slocum's parallax plates taken through a filter; Schlesinger's photographs taken with the film turned away from the objective). A few further experiments made expressly for the purpose are desirable.

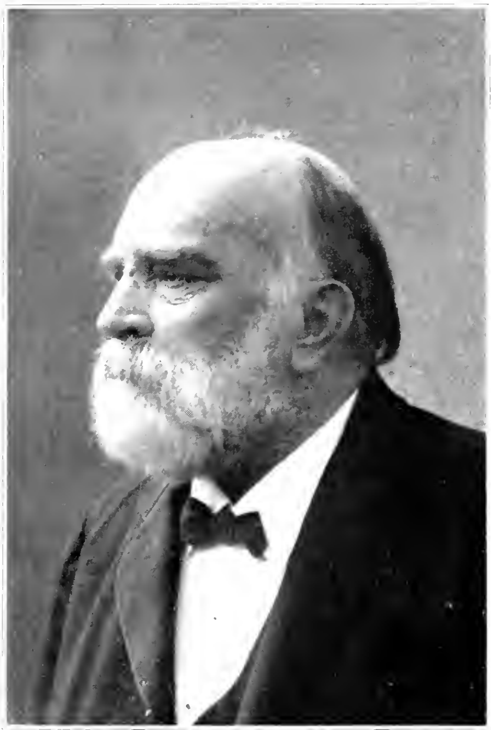
Second, great care has of course to be taken in order that no light of the stars shall reach the main plate without having passed through the corresponding extra-focal images. If, on the night in which the focal plate is obtained, we guide on the same star that was used for obtaining the extra-focal plate, all that is required is that the screen-plate can be inserted in the plate-holder absolutely in the same position in the two cases. Arrangements for the purpose seem easy of realization. We may further increase the security against error if, in taking the main plate, we put a circular diaphragm on the tube of the telescope.

In conclusion, I wish to remark that according to my experience images obtained through a blackened film, instead of being injured, are on the contrary usually rather superior to the ordinary images. The reduction of the images of the brighter stars must further greatly increase the accuracy of the measurement. It

seems probable, therefore, that the introduction of the screen-plate will rather diminish than increase the accidental errors. But even if it were not so, a slight sacrifice on the score of accidental error must almost seem a matter of indifference if we may thereby hope to realize freedom from systematic error.

J. C. KAPTEYN

December 1914



NILS CHRISTOFER DUNÉR

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NILS CHRISTOFER DUNÉR

By ANDERS ÅNGSTRÖM

By the death of Nils Christofer Dunér, late professor at the University of Upsala, who died on November 10, 1914, at the age of seventy-five years, the science of astronomy lost one of its most remarkable followers.

Dunér's career shows what important scientific work can be accomplished even with the aid of comparatively slight resources, provided that there is no lack of the necessary personal qualifications—unconquerable energy, capacity for scientific reasoning, and an ardent interest in the problem in hand.

The work of pioneers in the study of astronomy has often been carried on by the aid of the slender resources of small observatories. As an example of this may be adduced the career of Sir William Huggins, which was sketched not long ago in the pages of this *Journal*; another example is that of Dunér, whose work, especially in connection with double stars and the rotation of the sun, will always be looked upon as laying the foundations for future study in special departments of his science.

Dunér was born on May 21, 1839, at Billeberga, in the Swedish province of Scania, where his father was vicar. After having matriculated at Lund, he became extra assistant at the observatory there as early as 1858, and in 1864 he was appointed observer,

having taken his Doctor's degree earlier in the same year. This position provided Dunér with opportunities for developing considerable activity. After the newly established observatory at Lund had been provided with a larger refractor in 1864, Dunér began a systematic investigation of the double stars. The results of these comprehensive labors are brought together in his *Mésures micrométriques d'etoiles doubles, faites à l'Observatoire de Lund, suivies de notes sur leurs mouvements relatifs*, published in 1876. In this book Dunér discusses at length the results of earlier investigations, besides advancing a large number of new suggestions and describing many new investigations. The work is one of our principal authorities on double stars.

Probably it is in the choice of the problem to be attacked that scientific genius chiefly betrays itself. Methods grow antiquated and are improved upon, scientific results are modified and corrected, and, seen in the light of new discoveries, they get a new meaning. But as the most important task there always remains the keen sensing out of the real problems, on the solving of which science is built up, and which, vigorously debated and variously interpreted, incite succeeding generations to further investigations.

It is to this department that the following two great works of Dunér belong. These were *Sur les Etoiles à Spectre de la troisième classe*, published in 1884, and *Recherches sur la rotation du soleil*, published in 1891, after Dunér had been called to fill the chair of astronomy at Upsala. The latter of these two works proved to be his greatest triumph and suggested new problems. The former of them presents a penetrating investigation on the subject of the spectra of the red and reddish-colored stars (Vogel's third class). About twenty years after the appearance of this volume, Hale and Ellerman expressed themselves about it as follows: "In spite of the small aperture of his telescope, the low dispersion which was necessarily employed and the serious difficulties that are almost invariably encountered in visual observations of faint spectra, Dunér's results are of the highest value and have been confirmed in almost every particular by our photographs." In this work Dunér also presents an interesting and notable discussion regarding the development of the stars of the fourth order.

He shows that stars of type IV have a distinct tendency to collect in the Milky Way.

The work, however, upon which Dunér's reputation chiefly rests is his celebrated treatise on the rotation of the sun. Carrington (1853–1861), through a study of the movements of the sun-spots, had made the remarkable discovery that the rotation period of the sun declines from the equator to the poles; but on account of the limited frequency of the occurrence of the sun-spots, this observation could be effected only for the portion of the sun's surface lying between the equator and 40° of latitude. Dunér attacked this problem in a new and brilliant way, employing Doppler's principle for determining the rotations in different parts of the sun's disk. By measuring the shifts of the lines $\lambda\lambda$ 6302.709 Fe and 6302.975 A(O) on the periphery relatively to the center, he corroborated, as we know, Carrington's observations and found that the rotation period at the equator was 25.5 days, while at 15° from the poles it was 38.5 days. Several years later Dunér resumed his investigations, this time with the collaboration of one of his pupils, the present director of the Upsala Observatory, Professor Östen Bergstrand, and the results gained confirmed, on the whole, those obtained in the previous investigations.

As is well known, Dunér's method of determining the sun's rotation by means of an application of Doppler's principle has since been more widely used. By the application of this principle, Hale and his associates, at Mount Wilson, and Deslandres, at Meudon, have arrived at a clear conception of the movement in different parts of the solar atmosphere.

With regard to Dunér's other work, it may be mentioned that he conducted painstaking and successful investigations with regard to the variable stars Y Cygni and Z Herculis, belonging to the Algol type. He showed that the path of the one component around the other is markedly eccentric, and that the line of apsides rotates around the common center of gravity.

Dunér's astronomical work proves him to have been a brilliant and original scientist. He was a painstaking investigator of uncommon ability. Neither his talents nor his inclinations lay in the direction of theoretical speculations or comprehensive hypotheses,

and he accepted Newton's well-known *hypotheses non fingo*. For one who has accustomed himself to advance step by step, by means of painstaking scientific work, toward sure conclusions, the stride of theoretical speculation often seems to result in advances of slight worth. Dunér was bold in attacking important and exacting problems, but careful in the matter of drawing conclusions.

It is not only as an investigator that Dunér was active; he also rendered great service as a scientific organizer. Even as far back as 1861 and 1864, he took part in the Swedish expedition to Spitzbergen, where, in company with A. E. Nordenskiöld, he made preliminary investigations with the object of investigating the possibility of measuring a degree in those regions. Thanks to co-operation between Sweden and Russia, the measurement was effected, and Dunér took an active part in carrying on the work.

Further, he was one of the founders of the *Astronomische Gesellschaft;* he took an active part in astronomical meetings and the astro-photographic congresses, and he developed fruitful activity in the preparation of the international photographic map of the heavens. He was, besides, one of the editors of the *Astrophysical Journal.*

Among all the scientific distinctions that fell to the share of Dunér we may only mention that in 1887 he was awarded the Lalande Prize by the French Institute, and in 1892 the Rumford Gold Medal by the Royal Society in London.

Scientific investigation was, for Dunér, one of the necessities of life, and he devoted himself to his task with energy and zest. At the same time his work was stamped by that boyish curiosity which is such a remarkable trait in every great man of science. The writer remembers that the wall of his study was adorned by a French india-ink drawing representing an astronomer who, with every indication of enthusiasm, is telling a friend—who evidently does not share his joy—that he has discovered that, within a short time, the earth will collide with a comet. This astronomer might very well have been Dunér himself. He thought, with Poincaré, that the pursuit of truth is perhaps the most important object of our activities.

Dunér's interests were uncommonly all-embracing. He expressed himself with ease in most European languages, and as a boy he had taught himself Spanish, in order to be able to read *Don Quixote* in the original. After he had resigned his professorial chair in 1909, he occupied his leisure hours by translating Dante's *Divina Comedia*. His interest for comparative philology was so great that he was once known to have said that he would possibly have been a better linguist than astronomer. This we doubt, not because of his lack of ability in the study of languages, but because of his rare qualities as a scientist: his clear mind for inductive reasoning, and his great experimental genius.

UPSALA
January 1915

THE VARIATION WITH TEMPERATURE OF THE ELECTRIC FURNACE SPECTRA OF VANADIUM AND CHROMIUM[1]

By ARTHUR S. KING

The electric furnace spectra to be treated in this paper cover the range of wave-length from λ 3150 to λ 6850 for vanadium, and from λ 3550 to λ 7000 for chromium. The method of classification as to the initial temperature at which a spectrum line appears and its rate of increase in intensity as the temperature rises is similar to that used in previous studies of the spectra of iron[2] and titanium.[3]

APPARATUS AND METHODS

The tube resistance furnace was operated *in vacuo* according to the method described in previous papers. A distinct gain in the photography of the spectrum was obtained by the use of the vertical concave-grating spectrograph[4] recently mounted in the Pasadena laboratory. The spectra under examination being very rich in lines, especially in the region of shorter wave-length, the second order of this 15-foot grating was used to advantage in the crowded region extending to about λ 4500. The scale is approximately 1 mm = 1.85 A, and a range of about 850 A is obtained on a single plate. The first order gives a spectrum of high intensity and its scale was sufficient for the region toward the red. Seed "Gilt-Edge 27" plates were used throughout the spectrum, being bathed with the Wallace solution of pinacyanol, pinaverdol, and homocol for the region from λ 5000 into the red. A number of photographs of the whole spectrum were also made with a 1-meter concave grating to record the lines most persistent at low temperature and to observe the general changes in intensity with wave-length for the several furnace temperatures and for the arc.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 94.

[2] *Mt. Wilson Contr.*, No. 66; *Astrophysical Journal*, **37**, 239, 1913.

[3] *Mt. Wilson Contr.*, No. 76; *Astrophysical Journal*, **39**, 139, 1914.

[4] *Mt. Wilson Contr.*, No. 84; *Astrophysical Journal*, **40**, 205, 1914.

The three temperatures on which the classification for both vanadium and chromium is based were given by a Wanner pyrometer as 2000–2150° C. for the low, 2300–2350° C. for the medium, and 2500–2600° C. for the high temperature plates. With vanadium, 2000° C. appears to be about the lower limit for the appearance of a spectrum, though the lines produced at this temperature are fairly numerous. The case is different for chromium, the melting-point of which is considerably lower. Temperatures between 1700° and 1800° C. sufficed to give a number of the most persistent lines in this spectrum, which are listed in a separate table. The somewhat richer spectrum given at 2000°, however, was better suited to show the development of the lines from this into the medium and high temperatures.

The metals used in the furnace were metallic vanadium and crystalline chromium, both supplied by Eimer and Amend. These substances were of fair purity and as the furnace tubes used were of regraphitized Acheson graphite, the spectra obtained showed but few impurity lines of sufficient strength to be disturbing.

EXPLANATION OF THE TABLES

Wave-lengths.—The wave-lengths in the first column of Tables I and II are those given by Exner and Haschek[1] for the arc spectrum, supplemented occasionally by those of Hasselberg,[2] indicated by *H*, usually in cases where close doublets were not resolved by Exner and Haschek. Several chromium lines which are very wide in the arc in air were sometimes found to be resolved into as many as three sharp lines by the vacuum furnace. A vacuum arc furnished by special fittings inside the furnace chamber also gave sharp lines in these cases, which were measured from neighboring chromium lines and the wave-lengths entered in the table.

An asterisk after the wave-length denotes that an explanatory remark for the given line is to be found at the end of the table.

Arc intensities.—These were estimated by the writer from arc spectra taken on the same plates as the furnace spectra, the vanadium arc being given by the metal in the carbon arc, while that

[1] *Spektren der Elemente bei normalem Druck*, Leipzig, 1911.

[2] *Kgl. svenska vet. akad. handl.*, **26**, 1894; **32**, 1899; see also Kayser, *Handbuch der Spectroscopie*, **5**, 337; **6**, 750.

of chromium was formed between lumps of the metal. The arc photograph used was in each case of moderate exposure, the spectrum in general being comparable in intensity with that of the high-temperature furnace. Numerous nebulous lines, especially in the chromium table, are indicated by *n* after the intensity value. A vacuum source, either arc or furnace, serves in general to sharpen such lines. The letters *R* and *r*, both for arc and for furnace lines, indicate complete and partial self-reversal, respectively.

Furnace intensities.—In estimating the intensities of furnace lines an effort was made to obtain correct relative intensities for the lines for each temperature, a line distinctly outlined on the plate being given the intensity "1," a fainter appearance being indicated as "trace" (*tr*). The appearance of a line is usually much altered as the temperature rises, but the relative change of different lines with increase of temperature is shown in the tables.

Classification.—The method of assigning lines to classes is the same as that used for the titanium spectrum and is but slightly modified from the system used for iron. Class I lines are relatively strong at low temperatures and strengthen slowly at higher temperatures. Many of them are given the same intensity for the three temperatures and for the arc. Class II lines appear at low temperature but strengthen more rapidly than those of Class I as the tube becomes hotter. The basis of division between these classes, while sometimes rather arbitrary, is usually well defined. The lines of Class III are absent or faint at low temperature, appear at medium temperature, and are usually considerably stronger at high temperature. Class IV lines appear only at the highest furnace temperature, sometimes faintly at medium; while those of Class V are usually absent in the furnace or, if present, are faint compared to the arc intensity. For vanadium, as for titanium, this class is limited almost entirely to the enhanced lines, which are indicated by *V E*. Faint lines given in the arc tables are not entered in this list unless they appear also in the furnace.

The use of *A* after the class number indicates that the line in question is relatively weak in the arc, being usually not more than half as strong as in the high-temperature furnace. The significance of lines of this character will be considered in the discussion.

TABLE I

TEMPERATURE CLASSIFICATION OF VANADIUM LINES

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3164.96....	5	.....	.....	.....	V E	3241.30....	4	4	2	.....	III
3168.25....	6	.....	.....	.....	V E	3242.14....	1	2	tr	.....	III A
3170.47....	2	2	2	1	II	3243.42....	3	4	2	.....	III
3183.53....	30r	50R	30R	10r	II	3246.96....	1	1	.....	.....	IV
3184.11....	60R	100R	60R	20r	II	3248.81....	3	3	2	.....	III
3185.51....	40R	80R	40R	15r	II	3249.69....	10	8	6	5	II
3187.81....	10	tr	.....	.....	V E	3250.12....	2	2	1	.....	III
3188.21....	3	1	.....	.....	IV	3250.90....	4	.....	.....	.....	V E
3188.60....	10	tr	.....	.....	V E	3252.01....	4	.....	.....	.....	V E
3189.16....	1	1	.....	.....	IV	3253.00....	1	1	.....	.....	IV
3190.80....	15	1	.....	.....	V E	3254.91....	10	5	3	1	II
3194.07....	6	5	4	2	II	3255.79....	9	5	4	1	III
3194.53....	2	1	.....	.....	IV	3256.60....	1	1	.....	.....	IV
3194.70....	1	tr	.....	.....	IV	3257.00....	1	tr	.....	.....	IV
3195.05....	1	tr	.....	.....	IV	3259.67....	5	4	3	tr	III
3198.13....	20	30R	15r	6	II	3261.21....	6	3	1	.....	III
3199.97....	6	3	2	.....	III	3262.20....	5	4	1	.....	III
3201.35....	2	4	2	tr	III A	3263.39....	15	15r	8	5	II
3202.51....	25	35R	18r	6	II	3266.02....	5	2	tr	.....	IV
3204.30....	3	3	3	2	I	3266.20....	4	3	2	.....	III
3205.36....	5	2	1	.....	III	3267.83....	20	1	.....	.....	V E
3205.69....	15	6	4	3	II	3271.25....	20	1	.....	.....	V E
3207.01....	1	1	.....	.....	IV	3271.53....	3	2	2	.....	III
3207.51....	20	30R	15r	5	II	3271.80....	12	12r	7	4	II
3208.46....	6	.....	.....	.....	V E	3272.30....	1	1	tr	.....	III
3210.22....	4	3	1	.....	III	3273.16....	7	4	3	1	II
3210.54....	2	2	tr	.....	IV	3276.23....	20	1	.....	.....	V E
3211.68....	1	1	tr	.....	III	3278.02....	5	10r	6	3	II A
3212.57....	15	6	4	3	II	3279.97....	6	.....	.....	.....	V E
3214.04....	2	2	1	.....	III	3281.25....	3	.....	.....	.....	V E
3214.86....	6	.....	.....	.....	V E	3282.67....	5	.....	.....	.....	V E
3215.47....	4	4	3	2	II	3283.46....	15	15r	8	6	II
3217.20*...	10	7?	5?	2?	II ?	3284.47....	6	5	4	1	III
3218.45....	1	3	2	tr	III A	3288.55....	2	2	1	.....	III
3218.98....	5	3	2	tr	III	3289.51....	6	.....	.....	.....	V E
3225.76....	1	4	1	.....	III A	3291.81....	4	4	4	3	I
3226.23....	4	4	3	2	II	3295.56....	1	1	.....	.....	IV
3227.21....	3	3	1	.....	III	3298.28....	15	15r	10	8	II
3227.53....	4	2	tr	.....	IV	3298.85....	6	.....	.....	.....	V E
3228.31....	3	3	1	.....	III	3299.20....	3	3	2	.....	III
3229.72....	4	2	tr	.....	IV	3299.32....	1	1	.....	.....	IV
3230.76....	6	6	5	3	II	3300.08....	2	2	1	.....	III
3232.07....	2	.....	.....	.....	V E	3308.36....	3	4	4	1	III
3233.33....	6	4	3	tr	III	3309.03....	1	1	.....	.....	IV
3233.68....	2	.....	.....	.....	V E	3309.30....	8	4	3	1	II
3233.93....	3	.....	.....	.....	V E	3313.14....	2	2	1	.....	III
3234.86....	2	3	2	tr	III	3314.11....	3	2	tr	.....	IV
3238.00....	8	.....	.....	.....	V E	3316.01....	1	1	.....	.....	IV
3239.06....	1	1	.....	.....	IV	3319.14....	4	3	1	.....	III

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace: High Temp.	Furnace: Medium Temp.	Furnace: Low Temp.	Class
3319.91....	1	1	.....	.....	IV
3320.30....	3	3	2	.....	III
3321.80....	5	3	1	.....	III
3324.37....	1	1	.....	.....	IV
3324.55....	3	2	1	.....	III
3326.52....	1	1	.....	.....	IV
3327.30....	tr	tr	.....	.....	IV
3328.12....	2	1	.....	.....	IV
3328.54....	2	1	.....	.....	IV
3330.01....	12	8	6	3	II
3332.60....	tr	tr	.....	.....	IV
3333.70....	2	2	1	.....	III
3334.28....	tr	tr	.....	.....	IV
3336.35....	1	1	.....	.....	IV
3336.49....	2	1	.....	.....	IV
3336.93....	2	1	.....	.....	IV
3340.31....	1	1	.....	.....	IV
3342.42....	2	1	.....	.....	IV
3345.15....	tr	tr	.....	.....	IV
3356.50....	10	7	5	2	II
3362.2.....	1	tr	.....	.....	IV
3363.70....	4	5	3	tr	III
3365.71....	10	7	5	3	II
3367.02....	4	4	3	1	II
3367.18....	1	1	.....	.....	IV
3369.1.....	1	1	.....	.....	IV
3371.27....	3	1	.....	.....	IV
3372.94....	tr	1	.....	.....	IV A
3374.17....	3	4	2	.....	III
3376.20....	8	6	5	2	II
3377.51....	10	8	6	3	II
3377.75....	15	10	8	6	II
3379.49....	2	1	.....	.....	IV
3384.71....	5	5	4	1	III
3387.50....	2	1	.....	.....	IV
3389.64....	tr	tr	.....	.....	IV
3390.51....	2	2	1	.....	III
3390.91....	6	5	4	1	III
3394.90....	2	1	.....	.....	IV
3395.64....	3	3	1	.....	III
3396.65....	3	2	tr	.....	IV
3397.70....	6	5	4	1	III
3397.97....	4	5	4	1	III
3398.39....	1	1	.....	.....	IV
3400.55....	12	8	6	4	II
3401.49....	2	2	1	.....	III
3402.73....	9	7	5	3	II
3403.51....	5	4	1	.....	III
3405.09....	2	2	tr	.....	IV
3405.30....	6	5	4	2	II
3406.96....	6	6	4	1	III
3408.13....	3	3	2	tr	III
3408.60....	1	4	3	1	II A
3409.21....	4	3	1	.....	III
3411.10....	1	1	.....	.....	IV
3413.90....	1	1	.....	.....	IV
3414.32....	5	5	4	2	II
3416.65....	2	5	4	2	II A
3417.17....	5	5	4	2	II
3418.63....	5	5	4	2	II
3424.00....	3	3	1	.....	III
3425.20....	6	4	3	1	II
3425.37....	1	tr	.....	.....	IV
3426.06....	1	5	4	2	II A
3426.87....	1	2	1	.....	III A
3427.60....	1	1	.....	.....	IV
3432.19....	1	1	.....	.....	IV
3437.91....	1	1	.....	.....	IV
3439.13....	tr	tr	.....	.....	IV
3442.14....	2	1	.....	.....	IV
3442.45....	2	2	1	.....	III
3443.69....	1	1	.....	.....	IV
3445.00....	1	1	.....	.....	IV
3445.93....	2	2	tr	.....	IV
3447.23....	tr	tr	.....	.....	IV
3453.12....	tr	tr	.....	.....	IV
3453.65....	1	1	.....	.....	IV
3455.02....	3	2	tr	.....	IV
3455.36....	1	1	.....	.....	IV
3455.70....	1	1	.....	.....	IV
3455.95....	tr	tr	.....	.....	IV
3457.04....	4	4	2	.....	III
3457.23....	3	.....	.....	.....	V E
3460.23....	1	3	1	.....	III A
3463.53....	2	6	4	3	II A
3465.48....	tr	tr	.....	.....	IV
3482.31....	1	1	.....	.....	IV
3486.05....	6	2	1	.....	III
3487.14....	2	2	1	.....	III
3489.58....	4	4	2	.....	III
3490.40....	1	1	.....	.....	IV
3491.54....	tr	tr	.....	.....	IV
3493.32....	4	.....	.....	.....	V E
3496.40....	1	1	.....	.....	IV
3497.09....	3	3	1	.....	III
3498.34....	3	3	1	.....	III
3500.47....	1	1	.....	.....	IV
3500.96....	3	2	2	.....	III
3501.64....	4	4	3	tr	III
3503.31....	1	1	tr	.....	III
3504.60....	12	.....	.....	.....	V E
3505.39....	1	1	.....	.....	IV

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace High Temp.	Furnace Medium Temp.	Furnace Low Temp.	Class
3505.84	6	6	4	1	III
3506.99	3	3	1	.....	III
3516.35	1	1	.....	.....	IV
3517.44	12	tr	.....	.....	V E
3518.27	tr	tr	.....	.....	IV
3519.31	3	3	1	.....	III
3520.16	5	.....	.....	.....	V E
3522.00	2	.....	.....	.....	V E
3522.73	3	3	1	.....	III
3524.86	6	.....	.....	.....	V E
3525.90	1	1	tr	.....	III
3528.35	1	1	tr	.....	III
3529.89	10	8	6	4	II
3530.91	10	.....	.....	.....	V E
3533.87*	10	6	6	5	I
	6	8	4	2	II
3534.85	1	4	2	1	II A
3538.36	3	.....	.....	.....	V E
3540.66	1	5	3	1	II A
3542.77	1	3	2	1	II A
3543.62	8	6	5	3	II
3545.32	12	.....	.....	.....	V E
3545.49	8	6	5	3	II
3551.67	3	3	2	tr	III
3552.80	1	1	tr	.....	III
3553.43	6	6	5	3	II
3555.31	3	5	4	1	III
3555.87	2	3	3	1	II
3556.40	4	4	3	1	II
3556.96	15	tr	.....	.....	V E
3557.34	2	2	1	.....	III
3560.74	3	1	tr	.....	III
3561.55	1	1	tr	.....	III
3562.29	2	2	1	.....	III
3563.54	2	2	1	.....	III
3563.67	1	1	.....	.....	IV
3565.20	1	3	2	tr	III A
3566.32	4	4	2	tr	III
3569.07	3	3	1	.....	III
3569.19	1	3	2	1	II A
3571.16	4	4	2	1	II
3571.36	2	2	1	.....	III
3571.80	5	5	3	1	II
3572.45	1	2	1	.....	III A
3572.77	2	2	1	.....	III
3573.65	5	5	3	1	II
3574.90	3	4	2	1	II
3575.27	3	3	1	.....	III
3578.01	4	4	2	1	II
3579.24	2	2	1	.....	III
3579.46	1	tr	.....	.....	IV
3580.97	3	3	1	.....	III
3582.97	3	3	1	.....	III
3583.85*	8	12	8	3	II
3586.34	2	.....	.....	.....	V
3589.89	15	tr	.....	.....	V E
3591.23	1	1	tr	.....	III
3592.16	15	tr	.....	.....	V E
3592.32	1	4	3	1	II A
3592.70	3	2	1	.....	III
3593.49	12	.....	.....	.....	V E
3595.75	1	1	tr	.....	III
3598.26	1	1	tr	.....	III
3600.16	5	5	3	1	II
3604.24	1	tr	.....	.....	IV
3605.77	3	1	tr	.....	III
3606.85*	8	6?	4?	3?	II?
3609.42	3	3	1	.....	III
3616.86	3	2	1	.....	III
3617.44	1	1	tr	.....	III
3621.35	2	.....	.....	.....	V E
3622.79	2	1	tr	.....	III
3628.53	1	1	1	.....	III
3629.46	2	2	1	.....	III
3634.06	3	3	2	.....	III
3635.99	3	2	1	.....	III
3637.10	1	1	1	.....	III
3637.89	3	1	.....	.....	IV
3638.50	2	2	1	.....	III
3639.16	6	5	3	2	II
3640.20	2	2	1	.....	III
3641.24	4	4	3	1	II
3643.25	1	1	tr	.....	III
3643.99	5	5	3	1	II
3644.49	1	2	1	.....	III A
3644.87	8	8	6	3	II
3645.68	3	3	1	tr	II
3647.4	3	3	1	tr	II
3648.50	tr	tr	.....	.....	IV
3649.08	5	5	3	1	II
3652.54	2	2	1	tr	III
3654.82	2	1	tr	.....	III
3656.81	6	4	2	1	II
3657.62	2	6	5	4	I A
3659.60	2	1	tr	.....	III
3661.52	2	1	1	.....	III
3662.16	1	1	tr	.....	III
3663.71	15	8	5	4	II
3665.28	8	6	3	2	II
3667.89	15	8	5	4	II
3669.58	2	.....	.....	.....	V E
3671.37	10	8	6	6	I

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace High Temp.	Furnace Medium Temp.	Furnace Low Temp.	Class	λ (Exner and Haschek)	Arc	Furnace High Temp.	Furnace Medium Temp.	Furnace Low Temp.	Class
3672.55....	8	6	3	2	II	3737.60....	1	5	4	2	II A
3673.57....	12	10	5	4	II	3738.11....	5	4	3	1	II
3675.64....	3	3	1	.....	III	3738.89....	8	8	5	2	II
3675.89....	20	20r	20	20	I	3740.39....	6	5	3	1	II
3676.84....	10	8	4	2	II	3741.63....	6	5	3	1	II
3677.23....	2	6	6	6	I A	3744.04....	1	1	1	.....	III
3680.25....	15	6	5	3	II	3746.00....	8	.....	.....	.....	V E
3683.30....	30	30R	20	20	I	3747.26....	3	4	4	2	II
3684.50....	3	3	2	1	II	3748.11....	8n	5	3	1	II
3686.42....	8	8	6	5	I	3750.27....	1	1	tr	.....	III
3686.89....	1	1	tr	.....	III	3751.07....	6	.....	.....	.....	V E
3687.63*...	12?	6?	5?	3?	II?	3751.95....	5	8	6	4	II A
3688.23....	50	50R	30r	20	II	3753.44....	4	3	1	tr	II
3690.49....	40	40R	20	20	II	3755.85....	4	3	1	tr	II
3692.40....	50	50R	30r	20	II	3756.18....	3	5	4	2	II
3694.79....	3	4	2	1	II	3757.04....	tr	tr	.....	.....	IV
3695.50....	30	10	6	4	II	3758.70....	2	2	1	tr	II
3696.03....	40	50R	25r	20	II	3758.95....	1	1	tr	.....	III
3699.63....	3	4	3	1	II	3759.45....	4	3	1	tr	II
3700.49....	3	.....	.....	.....	V E	3760.95....	3	4	3	2	II
3700.78....	tr	1	tr	.....	III A	3761.56....	3	3	2	1	II
3703.73....	100	100R	40r	25	II	3763.29....	6	8	5	2	II
3704.16....	2	3	2	1	II	3764.95....	2	1	tr	.....	III
3704.85....	60	60R	25	20	II	3765.74....	1	1	tr	.....	III
3705.20....	30	30R	15	20	I	3766.55....	2	2	1	tr	II
3705.97....	1	1	tr	.....	III	3769.21....	4	4	3	1	II
3706.19....	4	4	3	2	II	3769.98....	1	1	tr	.....	III
3708.87....	6	5	4	2	II	3770.15....	2	1	1	.....	III
3711.56....	1	1	tr	.....	III	3770.67....	3	6	5	2	II A
3713.46....	1	1	tr	.....	III	3771.11....	8	.....	.....	.....	V E
3713.70....	1	1	tr	.....	III	3771.32....	1	4	3	1	II A
3714.11....	5	8	8	8	I A	3771.81....	1	5	5	4	I A
3715.00....	1	1	1	.....	III	3772.29....	2	1	tr	.....	III
3715.61....	10	.....	.....	.....	V E	3772.87....	2	1	tr	.....	III
3717.69....	1	1	tr	.....	III	3774.25....	3	1	tr	.....	III
3718.26....	2	.....	.....	.....	V E	3775.33....	3	5	3	1	II
3719.05....	4	2	1	.....	III	3775.82....	4	3	2	tr	III
3721.07....	1	1	tr	.....	III	3776.30....	4	3	2	1	II
3721.55*...	3	6	5	4	I A	3777.02....	2	3	2	tr	III
3722.14....	4	4	2	1	II	3777.30....	2	6	6	6	I A
3722.35....	3	1	1	.....	III	3777.61....	1	1	tr	.....	III
3723.47....	3	3	2	tr	III	3778.46....	2	.....	.....	.....	V E
3723.71....	1	1	tr	.....	III	3778.82....	25	25R	20	20	I
3727.48....	10	.....	.....	.....	V E	3779.78....	4	6	4	2	II
3728.48....	2	.....	.....	.....	V E	3781.55....	3	5	3	2	II
3729.18....	4	4	3	1	II	3781.89....	1	1	1	.....	III
3730.33*...	3	6	4	2	II A	3782.71....	3	3	2	1	II
3731.17....	2	1	tr	.....	III	3783.08....	1	1	1	.....	III
3732.21....	1	5	4	2	II A	3784.83....	2	5	7	6	I A
3732.90....	10	.....	.....	.....	V E	3784.95....	1	1	tr	.....	III
3734.57....	5	5	3	1	II	3787.30....	5	4	3	1	II

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3787.68....	3	3	3	1	II	3835.70....	4	6	6	3	II
3788.93....	1	1	1	.....	III	3836.19....	5	5	6	4	I
3790.47....	20	20R	20	20	I	3836.63....	1	tr	.....	.....	IV
3790.62....	8	8	5	3	II	3839.11....	10	7	7	6	I
3791.46....	2	8	6	5	I A	3839.52....	8	5	4	2	II
3793.79....	8	12	12	15	I A	3840.25....	4	5	4	3	I
3794.51....	2	1	tr	.....	III	3840.85....	60r	60R	40R	30	II
3795.12....	50	50R	35r	35	II	3842.02*...	5	12r	8	12	I A
3796.63....	3	3	1	tr	II	3842.84....	3	5	4	2	II
3798.39....	4	4	4	4	I	3843.10....	2	3	2	1	II
3798.80....	2	4	1	.....	III A	3843.61....	4	6	5	2	II
3799.41....	1	tr	.....	.....	IV	3844.58....	20	20r	20	20	I
3800.10....	25	25R	20	20	I	3845.01....	4	4	4	2	II
3803.01....	2	3	2	tr	III	3846.11....	3	2	1	1	II
3803.60....	25	25R	20	20	I	3847.49....	20	20R	20	20	I
3803.93....	6	6	5	2	II	3849.43....	6	5	5	4	I
3804.03....	6	10	8	10	I A	3851.34....	5	4	4	3	I
3804.72....	3	3	2	.....	III	3852.25....	2	4	3	2	II A
3805.05....	2	3	2	tr	III	3854.23....	1	1	1	.....	III
3806.92....	8	6	5	4	II	3855.50....	30	30R	30r	30	I
3807.63....	20	20R	20	20	I	3856.08....	60r	60R	50R	50	I
3808.26....	3	1	tr	.....	III	3858.82....	5	8	6	4	II A
3808.67....	40	40R	25r	25	II	3859.50....	6	8	7	4	II
3809.23....	1	1	tr	.....	III	3861.77....	6n	6	5	3	II
3809.74....	15	15	15	15	I	3862.40....	12	12r	12	15	I
3811.47....	2	1	1	.....	III	3864.02....	6	6	5	3	II
3813.63....	60	60R	25r	25	II	3864.26....	3	3	3	4	I
3815.66....	10	12	12	12	I	3864.70....	1	1	.....	.....	IV
3818.00....	8	12	12	15	I A	3865.05....	35	30R	25r	25	I
3818.12....	4	4	3	1	II	3867.48....	2	4	3	1	II A
3818.41....	60	60R	30r	30	II	3867.75....	15	15r	15	15	I
3818.91....	1	1	tr	.....	III	3870.73....	2	3	2	1	II
3820.11....	15	15r	15	15	I	3871.20....	8	6	6	4	I
3821.65....	15	15r	15	15	I	3872.91....	4n	6	4	2	II
3822.21....	30	30R	20r	20	I	3873.78....	4	5	4	2	II
3822.85....	1	1	tr	.....	III	3874.50....	1	1	1	.....	III
3823.05....	15	15r	15	15	I	3875.22....	35	30R	25r	25	I
3823.40....	15	15r	15	15	I	3875.55....	3	5	6	4	I
3823.55....	1	2	1	.....	III A	3876.02....	20	20R	20r	20	I
3823.92....	4	3	1	tr	II	3876.26....	20	20R	20r	20	I
3824.14....	5	6	6	3	II	3876.84....	1	1	tr	.....	III
3825.18....	1	1	tr	.....	III	3879.38*...	2?	4?	3?	?	III?
3825.47....	4	3	2	1	II	3879.80*...	3?	2?	2?	?	III?
3826.90....	6	8	5	3	II	3884.06....	3	3	3	1	II
3828.70....	60r	60R	30r	30	II	3884.60....	4	4	3	1	II
3828.93....	4	3	2	1	II	3885.00....	2	.....	.....	.....	V E
3830.44....	2	2	1	.....	III	3885.70....	1	1	.....	.....	IV
3831.99....	3	3	2	1	II	3885.93....	2	2	2	tr	III
3832.99....	4	3	2	.....	III	3886.74....	6	6	5	4	I
3833.36....	3	3	2	.....	III	3888.20....	2	2	1	.....	III
3834.95....	tr	tr	.....	.....	IV	3888.47....	3	3	2	tr	III

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace High Temp.	Furnace Medium Temp.	Furnace Low Temp.	Class	λ (Exner and Haschek)	Arc	Furnace High Temp.	Furnace Medium Temp.	Furnace Low Temp.	Class
3889.37....	1	1	tr	.....	III	3936.47....	5	5	6	5	I
3890.39....	25	25R	20	25	I	3937.69....	3	3	2	1	II
3891.30*...	4	3	2	1	II	3938.35....	3	2	1	tr	II
	2	4	3	1	II A	3939.04....	2n	2	1	tr	II
3892.63....	2	2	1	tr	II	3939.47....	4	4	3	1	II
3893.03....	25	25R	20	25	I	3940.75....	2	2	1	tr	II
3893.89....	1	1	tr	.....	III	3941.43....	3	3	2	1	II
3894.20....	4	4	3	2	II	3942.18....	6	6	5	3	II
3896.31*...	6	10	8	5	II	3943.80....	12	10	10	8	I
3896.80....	2	2	1	.....	III	3944.66....	1	1	tr	.....	III
3896.96....	2	2	1	.....	III	3945.32....	2	2	1	.....	III
3897.23....	6	4	3	2	II	3946.03....	1	1	tr	.....	III
3898.08*...	6	4?	3?	1	II	3950.39....	4	4	2	tr	III
3898.41....	5	4	3	1	II	3952.13....	6	.....	.....	.....	V E
3899.26....	4	.....	.....	.....	V E	3963.89....	4	2	1	tr	II
3900.29....	6	4	3	2	II	3964.65....	2	1	tr	.....	III
3901.29....	6	4	3	2	II	3968.25....	3	.....	.....	.....	V E
3901.83....	2	2	1	tr	II	3972.12....	2	2	1	.....	III
3902.41....	50r	50R	40R	40	I	3973.53....	2	2	1	.....	III
3902.68....	3	4	4	3	I	3975.50....	1	1	tr	.....	III
3903.38....	4	.....	.....	.....	V E	3979.30....	4	3	2	tr	III
3904.36....	1	3	2	1	II A	3979.56....	4	3	2	tr	III
3904.59*...	2	2	1	.....	III	3980.69....	3	2	1	.....	III
	3	3	2	tr	III	3984.50....	6	6	3	1	II
3906.90....	6	6	6	6	I	3984.76....	6	6	4	2	II
3907.32....	2n	1	1	tr	II	3988.98....	5	5	3	1	II
3908.47....	4n	3	2	tr	III	3990.77....	20	15	12	10	I
3909.55....	tr	tr	.....	.....	IV	3991.24....	1	1	tr	.....	III
3909.81....	4	4	2	tr	III	3992.98....	12	8	6	6	I
3910.03*...	20	20R	20r	25	I	3995.05....	1	1	1	.....	III
3910.93....	5	6	6	5	I	3997.28....	3	.....	.....	.....	V E
3912.37....	10	8	8	8	I	3998.91....	15	12	12	8	I
3913.01....	4	8	6	4	II A	4000.25....	1	1	tr	.....	III
3913.71....	2	1	tr	.....	III	4001.81....	1	1	.....	.....	IV
3914.01....	1	2	2	1	II A	4003.10....	2	.....	.....	.....	V E
3914.46....	5	5	5	3	I	4003.33....	tr	tr	.....	.....	IV
3915.26....	2	1	1	tr	II	4003.69....	2	1	.....	.....	IV
3915.51....	2	2	1	tr	II	4005.88....	6	.....	.....	.....	V
3916.53....	3	.....	.....	.....	V E	4009.92....	2	1	1	.....	III
3917.29....	2	2	2	1	II	4011.45....	3	3	1	.....	III
3920.14....	2	2	1	.....	III	4015.21....	1	tr	.....	.....	IV
3920.64....	5	5	5	4	I	4022.05....	3	1	.....	.....	IV
3922.09....	6	6	6	6	I	4023.32....	4	2	.....	.....	IV
3922.61....	12	12	12	12	I	4023.54....	5	.....	.....	.....	V E
3924.83....	10	8	5	4	II	4030.05....	2	6	5	tr	III A
3925.40....	10	15r	15	20	I	4031.39....	2	2	.....	.....	IV
3926.82....	1	1	1	.....	III	4032.02....	5	2	.....	.....	IV
3930.13....	10	6	6	6	I	4032.64....	1	tr	.....	.....	IV
3931.50....	5	4	4	2	II	4033.00....	2	6	6	tr	III A
3934.20....	20	15r	15	15	I	4034.86....	1	4	2	.....	III A
3935.30....	6	6	4	2	II	4035.76....	4	.....	.....	.....	V E

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
4036.90	2	.....	.....	.....	V E	4124.24	5	6	3	.....	III
4040.46	2	1	.....	.....	IV	4128.30	60	60R	35	40	I
4041.75	3	.....	.....	.....	V	4129.01	5	4	2	.....	III
4042.80	5	3	1	.....	III	4131.35	1	6	4	.....	III A
4048.76	4	8	8	3	II A	4132.15	60	60R	35r	40	I
4051.12	10	6	2	.....	III	4133.95	3	6	3	.....	III A
4051.58	12	6	2	.....	III	4134.65	60	60R	35r	40	I
4052.62	1	5	4	tr	III A	4136.25	4	3	1	.....	III
4053.43	3	2	tr	.....	IV	4136.56	3	8	8	1	III A
4057.26	10	4	2	.....	III	4139.42	4	4	tr	.....	IV
4064.13	10	5	1	.....	IV	4141.52	2	1	.....	.....	IV
4067.89	3	1	.....	.....	IV	4142.00	2	5	3	tr	III A
4068.15	4	8	8	3	II A	4142.81	2	6	4	tr	III A
4070.93	4	6	5	2	II	4143.06	2	2	1	.....	III
4071.68	8	5	2	.....	III	4149.01	2	5	5	tr	III A
4072.31	3	3	1	.....	III	4150.86	2	1	.....	.....	IV
4083.09	4	4	2	.....	III	4152.84	2	1	.....	.....	IV
4090.80*	25	12	?	12	I	4153.50	2	7	6	tr	III A
4092.11	3	3	1	.....	III	4156.02	1	5	2	.....	III A
4092.55	8	8	6	.....	III	4158.15	1	3	1	.....	III A
4092.89	50	50R	30r	40	I	4159.85	8	10	15	10	I
4093.65	5	6	4	.....	III	4160.56	1	5	2	.....	III A
4094.44	3	2	.....	.....	IV	4169.45	2	2	tr	.....	IV
4095.69	25	15	15	7	II	4171.49	3	4	tr	.....	IV
4097.09	3	2	.....	.....	IV	4174.20	5	4	2	.....	III
4099.99	60	60R	35r	40	I	4175.32	1	3	tr	.....	IV A
4102.37	20	15	15	6	II	4177.26	2	1	.....	.....	IV
4103.56	1	1	.....	.....	IV	4179.61	15	15	20	15	I
4104.53	12	7	2	.....	III	4181.05	1	1	.....	.....	IV
4104.94	15	12	5	.....	III	4182.26	2	2	.....	.....	IV
4105.37	60	60R	30r	35	I	4182.81	10	8	12	10	I
4107.63	4	4	2	.....	III	4190.03	12	12	15	12	I
4108.37	5	4	1	.....	III	4191.71	10	10	9	4	II
4109.20	2	2	.....	.....	IV	4195.77	1	1	.....	.....	IV
4109.98	50	50R	30r	40	I	4197.86	2	2	.....	.....	IV
4111.98	100R	100R	50R	50	I	4198.80	4	8	8	2	III A
4112.53	5	4	1	.....	III	4200.35	4	7	7	1	III A
4113.70	12	12	10	tr	III	4201.05	1	6	5	tr	III A
4114.70	3	2	.....	.....	IV	4210.03	20	15	20	15	I
4115.36	60	60R	30r	40	I	4216.54	1	4	2	1	II A
4115.6	2	3	1	.....	III	4218.88	4	10	10	2	III A
4116.64H	50	50R	50r	30	I	4219.67	2	6	4	tr	III A
4116.85H	4	15	15	10	I A	4222.49	2	1	.....	.....	IV
4118.37*	8	6	2	.....	III	4223.14	1	1	.....	.....	IV
4118.81	8	8	8	tr	III	4224.28	5	3	1	.....	III
4119.25	1	1	.....	.....	IV	4227.90	4	4	1	.....	III
4119.62	8	8	10	1	III	4229.86	4	3	1	.....	III
4120.71	8	8	8	tr	III	4232.66	15	9	4	.....	III
4121.15	1	tr	.....	.....	IV	4233.15	12	7	3	.....	III
4123.34	6	4	1	.....	III	4234.19	12	10	15	10	I
4123.71	60	60R	35r	40	I	4234.70	8	8	15	10	I

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.	
4235.91....	10	6	2	.....	III
4236.77....	1	4	2	.....	III A
4239.13....	2	1	.....	.....	IV
4240.25....	3	3	tr	.....	IV
4240.52....	4	6	2	.....	III
4241.48....	3	3	1	.....	III
4246.85....	1	1	.....	.....	IV
4252.96....	1	1	.....	.....	IV
4257.51....	6	4	2	.....	III
4259.46....	8	8	10	8	I
4261.34....	2	1	.....	.....	IV
4262.29....	6	5	2	.....	III
4265.28*...	8n	10	3	.....	III
4266.06....	1	tr	.....	.....	IV
4267.47....	1	tr	.....	.....	IV
4268.81....	20	12	8	1	III
4269.90....	5	4	1	.....	III
4270.48....	4	2	.....	.....	IV
4271.69....	12	10	6	tr	III
4277.13....	12	8	6	tr	III
4279.10....	2	4	1	.....	III A
4284.25....	15	10	8	tr	III
4286.57....	5	5	2	.....	III
4287.95....	4	2	.....	.....	IV
4288.96....	1	2	.....	.....	IV A
4291.47....	4	4	1	.....	III
4292.00....	15	10	4	.....	III
4296.29....	15	6	3	.....	III
4297.82....	12	5	3	.....	III
4298.19....	12	8	3	.....	III
4302.28....	tr	1	.....	.....	IV A
4303.68....	3	1	.....	.....	IV
4305.61....	3	3	.....	.....	IV
4306.40....	15	12	15	15	I
4307.36....	12	10	12	12	I
4309.67....	2	1	.....	.....	IV
4309.99....	20	20r	20	15	I
4314.06....	3	2	.....	.....	IV
4330.26....	30	30r	20	25	I
4332.56....	1	1	.....	.....	IV
4333.03....	30	30r	20	20	I
4334.28....	4	8	2	.....	III A
4336.30....	2	1	.....	.....	IV
4341.21....	40	40r	20	25	I
4342.37....	4	5	2	.....	III
4343.00....	6	4	2	.....	III
4350.88....	1	1	.....	.....	IV
4351.00....	2	12	6	tr	III A
4352.64....	2	1	.....	.....	IV
4353.08....	50	50R	30r	40	I
4353.51....	2	1	.....	.....	IV
4355.14....	5	5	1	.....	IV
4356.12....	10	12	15	15	I
4356.96....	1	1	.....	.....	IV
4357.64....	2	2	.....	.....	IV
4360.76....	3	3	.....	.....	IV
4361.58....	2	2	.....	.....	IV
4363.52....	1	1	.....	.....	IV
4363.70....	5	12	12	4	II A
4364.39....	4	2	.....	.....	IV
4365.90....	3	2	.....	.....	IV
4368.23....	10	10	10	15	I
4368.79....	4	3	.....	.....	IV
4369.24....	2	2	.....	.....	IV
4373.42....	4	4	tr	.....	IV
4374.01....	4	5	1	.....	IV
4375.25....	1	1	.....	.....	IV
4375.50....	4	2	.....	.....	IV
4376.97....	1	tr	.....	.....	IV
4378.07....	2	2	.....	.....	IV
4379.41....	150r	150R	75r	60	II
4380.74....	4	5	1	.....	IV
4381.20....	1	4	1	.....	IV A
4384.36....	1	9	6	1	III A
4384.91....	125r	125R	60r	50	II
4385.50....	1	1	.....	.....	IV
4387.40....	3	8	3	.....	III A
4390.19....	100	100R	50r	40	II
4390.81....	1	1	.....	.....	IV
4391.85....	2	2	.....	.....	IV
4392.27....	5	12	15	5	II A
4393.26....	4	4	1	.....	III
4394.03....	4	8	5	.....	III A
4394.99....	3	4	2	.....	III
4395.45....	80	80R	40	35	II
4397.54....	1	tr	.....	.....	IV
4399.59....	2	3	1	.....	III
4400.78....	60	60r	30	30	II
4403.85....	4	5	2	.....	III
4405.23....	4	10	8	1	III A
4406.30*...	6	20	5	.....	III A
4406.88....	80	80R	50r	50	I
4407.80....	70	70R	40r	40	I
4408.35....	70	70R	40r	40	I
4408.70....	90	90R	60r	50	I
4412.33....	12	12	15	10	I
4413.86....	2	6	2	.....	III A
4414.73....	2	2	.....	.....	IV
4416.63....	20	20r	20	20	I
4416.80....	2	6	1	.....	IV A
4420.12....	12	12	15	12	I
4421.79....	20	20r	20	20	I

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
4422.41....	3	3	.....	.....	IV	4492.49*...	1	2	.....	.....	IV A
4422.65....	2	1	.....	.....	IV	4495.17....	1	1	.....	.....	IV
4423.39*...	8	20	8	tr	III A	4496.25....	8	8	2	.....	III
4424.10....	2	1	.....	.....	IV	4497.03H..	5	6	2	.....	III
4424.75....	4	10	2	.....	III A	4497.55....	2	1	.....	.....	IV
4425.90....	4	8	2	.....	III A	4498.30....	tr	1	.....	.....	IV A
4426.20....	20	20r	20	20	I	4501.01....	1	1	.....	.....	IV
4427.48....	5	4	2	.....	III	4501.44....	1	1	.....	.....	IV
4428.70....	15	12	15	15	I	4502.18....	8	10	6	tr	III
4429.98....	15	15	20	20	I	4506.30H..	2	2	.....	.....	IV
4430.71....	3	4	.....	.....	IV	4506.41H..	1	tr	.....	.....	IV
4433.05*...	1	6	1	.....	IV A	4506.77....	2	2	.....	.....	IV
4434.73....	5	7	2	.....	III	4509.49....	3	3	.....	.....	IV
4436.30....	15	15	15	20	I	4511.65....	2	2	.....	.....	IV
4438.01....	20	20r	20	25	I	4513.81....	2	2	.....	.....	IV
4439.15....	1	1	.....	.....	IV	4514.39....	6	5	2	.....	III
4441.89....	25	25r	20	30	I	4515.74....	2	2	.....	.....	IV
4443.40....	5	3	.....	.....	IV	4517.73*...	3	1	.....	.....	IV
4444.40....	20	20r	20	25	I	4520.35....	3	10	2	.....	III A
4445.98....	1	1	.....	.....	IV	4520.71....	2	.....	.....	.....	V E
4449.73....	5	7	3	.....	III	4523.03....	tr	tr	.....	.....	IV
4451.10....	4	3	.....	.....	IV	4524.41....	15	10	5	.....	III
4452.23....	20	12	12	1	III	4525.34....	5	5	1	.....	IV
4452.89....	2	3	.....	.....	IV	4528.18....	5	2	.....	.....	IV
4453.31....	1	1	.....	.....	IV	4529.47....	4	2	.....	.....	IV
4456.69....	3	1	.....	.....	IV	4529.80....	8	8	3	.....	III
4457.67....	15	15	20	30	I	4530.99....	4	1.	.....	.....	IV
4457.96....	8	8	3	.....	III	4534.11....	4	1	.....	.....	IV
4458.58....	1	1	.....	.....	IV	4535.74....	1	1	.....	.....	IV
4459.99....	30	30R	25	35	I	4537.84....	6	6	1	.....	IV
4460.58....	50	50R	30r	40	I	4540.19....	6	5	1	.....	IV
4461.20....	4	3	.....	.....	IV	4545.59....	25	15	8	1	III
4462.59....	20	12	10	1	III	4549.80....	10	5	.....	.....	IV
4464.44....	2	2	.....	.....	IV	4552.04....	3	4	tr	.....	IV
4464.94....	2	3	.....	.....	IV	4553.25....	7	4	.....	.....	IV
4465.69....	2	3	.....	.....	IV	4560.95....	20	12	6	tr	III
4467.05....	2	4	.....	.....	IV A	4570.62....	6	4	1	.....	III
4467.82....	1	1	.....	.....	IV	4572.01....	15	8	5	.....	III
4468.20....	8	9	3	.....	III	4577.38....	40	30r	25	35	I
4468.96....	4	4	1	.....	III	4578.90....	15	10	4	.....	III
4469.91....	15	10	8	1	III	4579.29....	7	5	1	.....	IV
4471.95....	1	1	.....	.....	IV	4580.62....	40	30r	25	35	I
4473.43....	1	1	.....	.....	IV	4581.45....	2	2	.....	.....	IV
4474.26....	10	10	3	.....	III	4583.98....	5	3	1	.....	III
4474.93....	12	12	5	tr	III	4586.11....	2	2	tr	.....	IV
4476.08....	2	3	.....	.....	IV	4586.59....	50	30R	30	40	I
4480.21....	6	6	2	.....	III	4588.98....	1	tr	.....	.....	IV
4489.09....	20	15	8	tr	III	4591.43....	12	4	tr	.....	IV
4491.00....	5	6	2	.....	III	4594.36....	60	40R	40	50	I
4491.35....	2	3	1	.....	III	4603.17....	2	1	.....	.....	IV
4491.64....	1	1	.....	.....	IV	4606.33....	15	15	20	15	I

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace: High Temp.	Furnace: Medium Temp.	Furnace: Low Temp.	Class
4609.79	4	3	1	.....	III
4611.08	2	4	2	.....	III A
4611.91	2	2	.....	.....	IV
4619.88	8	2	.....	.....	IV
4619.97H	25	20	20	15	I
4624.55	8	12	8	1	III
4626.64	7	12	7	1	III
4635.34	15	10	20	15	I
4636.32	2	2	.....	.....	IV
4640.25	8	10	6	tr	III
4640.92	7	10	5	tr	III
4644.69	3	4	2	.....	III
4646.16	1	4	3	.....	III A
4646.60	15	12	12	1	III
4666.31*	4	3?	3?	.....	III?
4670.70	25	15	20	3	III
4687.08*	6	?	?	.....	?
4699.49*	3	?	?	.....	?
4705.26*	4	?	?	.....	?
4706.35*	8	5?	?	.....	?
4706.77*	12	5?	?	.....	?
4707.63*	4	8?	2?	.....	III A
4709.91*	4	4?	?	.....	?
4710.75*	12	4?	?	.....	?
4714.30*	10	?	?	.....	?
4716.10*	5	5?	?	.....	?
4717.89	10	5	1	.....	IV
4721.75	6	3	1	.....	III
4723.09	8	4	1	.....	III
4729.71	6	5	2	.....	III
4730.59	3	3	1	.....	III
4737.92	1	1	.....	.....	IV
4738.52	1	1	.....	.....	IV
4739.29	1	2	.....	.....	IV A
4742.81	5	4	tr	.....	IV
4746.81	5	5	1	.....	IV
4747.33	1	1	.....	.....	IV
4748.72	7	7	2	.....	III
4751.22	8	9	2	.....	III
4751.80	6	6	2	.....	III
4754.19	7	6	1	.....	IV
4757.55H	4	4	1	.....	III
4757.68H	8	8	2	.....	III
4758.94	2	4	1	.....	III A
4765.86	1	1	.....	.....	IV
4766.81	10	8	3	.....	III
4773.30	1	tr	.....	.....	IV
4776.54H	10	8	3	.....	III
4776.70H	5	4	1	.....	III
4778.61	tr	tr	.....	.....	IV
4781.55	tr	1	.....	.....	IV A

λ (Exner and Haschek)	Arc	Furnace: High Temp.	Furnace: Medium Temp.	Furnace: Low Temp.	Class
4784.68	5	15	15	5	II A
4786.72	20	8	4	.....	III
4793.12	3	3	.....	.....	IV
4795.30	3	1	.....	.....	IV
4797.12	20	8	4	.....	III
4798.14	2	3	.....	.....	IV
4799.20	1	1	.....	.....	IV
4799.97	5	12	15	7	II A
4807.72	25	8	5	.....	III
4819.20	2	1	.....	.....	IV
4827.63	30	25	30	30	I
4828.99	1	1	.....	.....	IV
4830.86	1	1	.....	.....	IV
4831.82	35	35	30	30	I
4832.61	30	30	25	25	I
4833.20	3	6	1	.....	IV A
4833.99	1	tr	.....	.....	IV
4843.17	2	2	.....	.....	IV
4848.78	3	4	1	.....	III
4849.00	1	tr	.....	.....	IV
4851.69	40	40r	30	30	I
4859.31	2	1	.....	.....	IV
4862.79	5	5	1	.....	IV
4864.91	40	30r	25	20	I
4875.65	40	30r	25	25	I
4877.40	tr	1	.....	.....	IV A
4880.74	8	12	5	.....	III
4881.73	50	40R	30	30	I
4882.38	2	4	1	.....	III A
4885.81	2	2	.....	.....	IV
4887.00	2	6	2	.....	III A
4890.29	1	1	.....	.....	IV
4891.41	1	1	.....	.....	IV
4891.80	4	4	1	.....	III
4894.41	4	4	1	.....	III
4896.60	1	4	.....	.....	IV A
4900.21	tr	1	.....	.....	IV A
4900.81	6	4	tr	.....	IV
4904.58*	12	12	4	.....	III
4905.10	3	3	tr	.....	IV
4906.09	tr	1	.....	.....	IV A
4908.86	1	2	.....	.....	IV A
4916.42	2	1	.....	.....	IV
4925.84	10	10	8	1	III
4932.21	4	8	4	.....	III A
4933.80	1	1	.....	.....	IV
4942.98	1	2	.....	.....	IV A
4966.27	2	1	.....	.....	IV
5002.50	4	4	.....	.....	IV
5014.79	5	3	1	.....	III
5047.45*	1	2?	1?	.....	IIIA?

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
5051.81*...	2	1	.....	.....	IV	5517.40....	1	8	4	2	II A
5064.30*...	3	.....	.....	.....	V	5534.02....	1	1	.....	.....	IV
5105.32*...	2	3?	1?	.....	III?	5542.91....	1	6	4	2	II A
5128.70*...	7	6?	4?	.....	III	5446.13....	2	7	4	tr	III A
5138.60*...	5	3?	2?	.....	III	5447.26....	8	12	9	4	II
5148.87*...	4	2?	1?	.....	III?	5557.67....	1	6	5	2	II A
5159.52*...	3	?	?	.....	III?	5558.98....	3	5	3	.....	III
5166.93....	1	1	.....	.....	IV	5561.90....	2	4	2	.....	III A
5170.11....	1	1	tr	.....	III	5574.20....	1	4	2	1	II A
5176.95....	4	2	1	.....	III	5584.77....	10	10	10	8	I
5178.73....	1	1	.....	.....	IV	5586.21....	2	2	1	.....	III
5179.30....	1	tr	.....	.....	IV	5588.69....	1	3	1	.....	III A
5180.96....	1	1	.....	.....	IV	5592.63....	12	10	8	8	I
5183.05....	1	1	.....	.....	IV	5593.24....	1	10	5	4	II A
5192.22....	1	1	.....	.....	IV	5598.10....	1	2	1	.....	III A
5193.20....	7	5	4	.....	III	5601.60....	2	3	2	.....	III
5193.84....	1	1	tr	.....	III	5604.41....	1	1	.....	.....	IV
5195.00....	10	7	2	.....	III	5605.18....	8	10	10	5	II
5195.65....	5	3	1	.....	III	5624.87....	20	12	12	15	I
5206.80....	1	1	tr	.....	III	5625.18....	10	10	10	5	II
5213.82....	1	1	tr	.....	III	5626.27....	8	12	10	6	II
5216.76....	3	2	tr	.....	IV	5627.85....	30	12	15	20	I
5225.90....	3	2	1	.....	III	5632.71....	1	8	6	4	II A
5233.87....	2	2	tr	.....	IV	5646.29....	10	12	10	5	II
5234.26....	8	4	2	.....	III	5651.70....	1	1	.....	.....	IV
5240.35....	1	1	tr	.....	III	5657.10....	1	1	.....	.....	IV
5241.03....	9	5	2	.....	III	5657.70....	12	10	10	6	II
5261.12....	1	1	.....	.....	IV	5665.49....	1	1	.....	.....	IV
5271.20....	1	1	.....	.....	IV	5668.55....	12	12	10	6	II
5272.87....	1	1	.....	.....	IV	5671.05....	30	20	20	20	I
5282.70....	1	1	.....	.....	IV	5683.37....	2	2	1	.....	III
5330.58....	1	3	1	.....	III A	5687.93....	1	1	.....	.....	IV
5353.56....	5	3	1	.....	III	5691.3.....	1	1	.....	.....	IV
5383.61....	2	1	.....	.....	IV	5698.71....	60	30	30	40	I
5385.33....	3	1	tr	.....	III	5703.81....	40	20	20	30	I
5388.50....	1	1	tr	.....	III	5704.6.....	2	1	.....	.....	IV
5398.12....	1	tr	.....	.....	IV	5706.25....	2	1	.....	.....	IV
5402.17....	8	5	2	.....	III	5707.20....	30	20	20	25	I
5415.47....	10	6	2	.....	III	5707.95....	1	1	.....	.....	IV
5418.29....	2	1	.....	.....	IV	5709.11....	2	2	1	.....	III
5424.28....	4	3	1	.....	III	5716.37....	3	1	.....	.....	IV
5434.40....	3	2	tr	.....	IV	5725.80....	6	5	2	.....	III
5437.89....	1	1	.....	.....	IV	5727.28....	60	30	30	40	I
5458.31....	1	1	.....	.....	IV	5727.89....	20	20	20	8	II
5487.42....	2	3	1	.....	III	5730.10....	tr	1	.....	.....	IV A
5488.10....	10	5	3	.....	III	5731.50....	30	35	30	12	II
5490.19....	2	2	1	.....	III	5733.29....	1	1	.....	.....	IV
5505.09....	2	3	1	.....	III	5733.63....	1	tr	.....	.....	IV
5507.95....	8	6	2	.....	III	5734.21....	5	4	2	.....	III
5511.40....	1	1	.....	.....	IV	5737.25....	25	20	20	12	II
5515.27....	1	15	10	6	II A	5743.66....	18	20	20	8	II

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
5747.92....	2	2	1	.....	III	6135.49....	15	15	15	10	II
5749.05....	4	4	3	.....	III	6150.32....	15	20	25	30	I
5750.89....	2	2	1	.....	III	6170.55....	8	20	20	15	I A
5752.92....	3	4	2	.....	III	6182.06....	1	4	2	.....	III A
5761.67....	2	7	4	tr	III A	6189.55....	3	15	15	4	II A
5772.65....	6	6	5	.....	III	6190.70....	1	4	2	.....	III A
5776.90....	4	15	10	3	II A	6199.40....	30	30	30	35	I
5782.81....	2	6	3	.....	III A	6214.04....	15	20	20	15	I
5783.12....	1	1	.....	.....	IV	6214.93....	1	1	.....	.....	IV
5783.81....	2	2	1	.....	III	6216.52....	30	30	30	35	I
5784.64....	5	3	1	.....	III	6218.52....	3	2	.....	.....	IV
5786.43....	7	4	2	.....	III	6221.39....	1	7	3	.....	III A
5788.80....	3	4	3	.....	III	6224.70....	15	20	20	15	I
5790.80....	1	2	1	.....	III A	6230.92....	30	25	25	30	I
5800.2.....	2	2	tr	.....	IV	6233.31....	12	20	20	15	I A
5807.38....	3	2	1	.....	III	6236.49....	1	1	.....	.....	IV
5815.00....	1	1	.....	.....	IV	6238.38....	tr	tr	.....	.....	IV
5817.30....	3	4	2	.....	III	6240.30....	6	15	15	8	II A
5817.85....	5	2	1	.....	III	6243.02....	15	20	20	25	I
5826.83....	1	1	1	.....	III	6243.37....	30	20	20	30	I
5830.95....	7	3	1	.....	III	6243.70....	3	8	4	.....	III A
5846.65....	8	4	1	.....	III	6245.35....	2	12	8	3	II A
5850.57....	2	4	2	.....	III A	6249.37....	tr	1	.....	.....	IV A
5853.96....	1	2	tr	.....	IV A	6252.02....	30	30	30	30	I
5855.70....	tr	1	.....	.....	IV A	6257.03....	8	20	20	10	II A
5863.41....	tr	1	.....	.....	IV A	6258.73....	8	25	30	10	II A
5924.82....	2	4	3	.....	III A	6261.39....	5	25	20	6	II A
5979.11....	2	4	2	.....	III A	6266.49....	7	20	20	8	II A
5981.02....	2	7	4	tr	III A	6268.98....	8	25	30	10	II A
5984.85....	1	4	2	.....	III A	6274.80....	15	20	20	20	I
6002.52....	2	7	4	1	II A	6282.52....	2	3	1	.....	III
6002.89....	4	10	8	3	II A	6285.32....	20	20	20	25	I
6008.90....	tr	4	2	.....	III A	6293.02....	20	20	20	25	I
6016.34....	1	1	.....	.....	IV	6296.69....	15	20	20	20	I
6018.16....	tr	4	2	.....	III A	6298.89....	tr	1	.....	.....	IV A
6022.00....	tr	tr	.....	.....	IV	6304.60....	2	1	.....	.....	IV
6025.64....	1	2	1	.....	III A	6309.89....	1	1	.....	.....	IV
6039.95....	25	15	15	15	I	6311.70....	3	2	1	.....	III
6048.89....	tr	2	1	.....	III A	6318.59....	tr	1	.....	.....	IV A
6058.33....	5	20	10	3	II A	6321.49....	2	1	.....	.....	IV
6063.57....	tr	1	tr	.....	III A	6324.87....	2	3	1	.....	III
6067.47....	1	1	tr	.....	III	6327.00....	6	8	5	1	III
6081.70....	25	20	20	20	I	6339.23....	5	7	4	tr	III
6087.70....	1	3	1	.....	III A	6344.12....	1	1	.....	.....	IV
6090.45....	50	25	25	25	I	6349.61....	5	7	4	tr	III
6104.91....	tr	4	2	.....	III A	6355.72....	1	2	1	.....	II A
6107.21....	2	8	4	tr	III A	6357.47....	4	6	4	.....	III
6111.90....	25	25	25	12	II	6358.99....	3	4	2	.....	III
6119.70....	40	20	20	25	I	6361.42....	3	4	2	.....	III
6128.49....	2	6	4	tr	III A	6374.67....	1	2	1	.....	III A
6135.21....	2	4	3	.....	III A	6379.53....	3	4	1	.....	III

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
6393.47....	2	3	1	.....	III	6543.71....	3	15	8	1	III A
6417.19....	tr	1	.....	.....	IV A	6550.26....	1	1	.....	.....	IV
6418.87....	tr	1	.....	.....	IV A	6558.23....	2	7	3	tr	III A
6423.50....	tr	1	.....	.....	IV A	6566.10....	2	8	4	tr	III A
6425.3.....	1	1	.....	.....	IV	6579.19....	1	4	3	.....	III A
6430.68....	3	5	3	.....	III	6606.22....	5	15	15	3	III A
6431.82....	2	4	3	.....	III A	6608.06....	2	5	3	.....	III A
6433.37....	1	3	2	.....	III A	6623.80....	tr	2	tr	.....	IV A
6435.35....	1	3	2	.....	III A	6625.10....	5	15	15	3	III A
6438.25....	tr	1	.....	.....	IV A	6633.53....	1	4	1	.....	III A
6445.35....	tr	1	.....	.....	IV A	6644.02....	tr	2	tr	.....	IV A
6448.02....	tr	1	.....	.....	IV A	6662.6.....	tr	2	tr	.....	IV A
6451.20....	tr	1	.....	.....	IV A	6753.20....	5	15	15	3	III A
6452.55....	8	20	15	4	II A	6766.70....	4	12	12	2	III A
6467.19....	1	4	2	.....	III A	6785.19....	3	10	10	1	III A
6488.22....	2	2	tr	.....	IV	6812.63....	2	7	6	tr	III A
6490.94....	1	1	.....	.....	IV	6830.16*...	1	2	2	.....	III A
6504.38....	8	20	15	4	II A	6832.67*...	1	3	3	.....	III A
6508.96....	1	1	tr	.....	III	6842.11*...	1	2	2	.....	III A
6531.65....	20	20	20	6	II						

REMARKS ON TABLE I

λ	
3217.20	Furnace line may be partly Ti.
3533.87	Components of double line about 0.07 A apart.
3583.85	Wide in furnace and arc. May be double.
3606.85	Blend with Fe.
3687.63	Blend with Fe.
3721.55	Probably double.
3730.33	Wide in furnace and arc. Probably double.
3842.02	Exceptionally strong at low temperature.
3879.38, 3879.80	Disturbed by carbon.
3891.30	Double line, not fully resolved.
3896.31	Probably double.
3898.08	Blend with Fe.
3904.59	Double line, not fully resolved.
3910.03	Probably double. Reversal is stronger on red side.
4090.80	Blended with impurity line on medium temperature plates.
4118.37	Double line, not resolved.
4265.28	Wide in furnace and arc.
4406.30	Probably double.
4423.39	Probably double.

4433.05	Wide in furnace.
4492.49	Wide in furnace.
4517.73	Wide in furnace.
4666.31	Disturbed by carbon.
4687.08 to 4716.10	These lines are in a dense carbon fluting and intensities are uncertain. They are not strong in the furnace and probably belong in Classes III and IV.
4904.58	Probably double.
5047.45 to 5159.52	Disturbed by carbon.
6830.16 6832.67 6842.11	λ's according to Shaw, *Astrophysical Journal*, **30**, 127, 1909.

TABLE II

TEMPERATURE CLASSIFICATION OF CHROMIUM LINES

λ (Exner and Haschek)	Arc	Furnace High Temp.	Furnace Medium Temp.	Furnace Low Temp.	Class	λ (Exner and Haschek)	Arc	Furnace High Temp.	Furnace Medium Temp.	Furnace Low Temp.	Class
3550.81	4	.....	.....	.....	V	3743.10	5	4	1	.....	III
3558.66	8n	5	1	.....	IV	3743.71	20	8	4	2	II
3566.28	10n	5	1	.....	IV	3744.03	20	6	3	2	II
3572.90	2	2	.....	.....	IV	3744.67	5	4	2	.....	III
3573.80	5	3	1	.....	III	3747.42	2	1	tr	.....	III
3574.19	4	2	1	.....	III	3748.75	5	3	1	.....	III
3574.97	5	2	1	.....	III	3749.15	20	10	5	1	III
3575.06	3	1	.....	.....	IV	3751.34	1	tr	.....	.....	IV
3578.81*	200R	400R	200R	100r	II	3755.99	2	1	tr	.....	III
3584.47	12n	.....	.....	.....	V	3757.30	5	3	1	.....	III
3587.12	2n	.....	.....	.....	V	3757.80	12	5	3	tr	III
3593.64*	160R	320R	160R	80r	II	3758.18	6	4	2	.....	III
3599.54	1	1	.....	.....	IV	3767.60	4	3	tr	.....	IV
3601.81	6	3	2	.....	III	3768.23H	3n	3	1	.....	III
3602.70	1	1	tr	.....	III	3768.37	12	8	3	1	II
3603.89*	3	?	1	.....	III	3768.86	5	4	1	.....	III
3605.49*	140R	280R	140R	70r	II	3769.14	1	1	tr	.....	III
3609.65	3	2	1	.....	III	3786.38	2	1	.....	.....	IV
3610.20	2	1	tr	.....	III	3789.87	4	8	5	2	II A
3613.80	1	1	.....	.....	IV	3790.35	2	1	.....	.....	IV
3615.77	4	10r	5	3	II A	3790.62	5	2	tr	.....	IV
3619.57	2	2	.....	.....	IV	3791.52	7	4	1	.....	III
3632.98	6	5	2	.....	III	3792.29	7	4	1	.....	III
3636.70	10	5	3	1	II	3792.55	1	1	.....	.....	IV
3639.97	15	5	4	1	II	3793.44	7	4	1	.....	III
3640.55	4	3	1	.....	III	3794.00	7	4	1	.....	III
3641.61	3	3	1	.....	III	3794.75	5	3	1	.....	III
3641.99	8	4	2	.....	III	3797.29	7	4	1	.....	III
3646.30	1	1	.....	.....	IV	3797.85	12	6	3	.....	III
3648.66	2	3	1	.....	III	3804.95	15	8	4	1	III
3649.11	10	5	3	tr	III	3806.97	4	1	.....	.....	IV
3654.07	8	4	2	.....	III	3808.06	6	3	1	.....	III
3656.40	10	5	3	tr	III	3810.4	2n	1	.....	.....	IV
3663.01	2	2	1	.....	III	3812.36	5	2	.....	.....	IV
3663.36	5	4	2	.....	III	3814.71	4	1	.....	.....	IV
3666.14	1	1	.....	.....	IV	3815.60	10	5	3	.....	III
3666.78	3	1	.....	.....	IV	3817.96	4	3	2	.....	III
3676.45	2	1	.....	.....	IV	3818.62	8	5	2	.....	III
3679.18	1	1	.....	.....	IV	3819.72	15	6	3	.....	III
3679.97	2	2	1	.....	III	3823.68	8	8	7	4	II
3681.82	1	1	.....	.....	IV	3825.51	10	3	1	.....	III
3685.70	5n	5	3	.....	III	3826.58	10	5	2	.....	III
3686.95	6n	5	2	.....	III	3830.20	15n	.....	.....	.....	V
3687.42	5n	3	1	.....	III	3831.20	5	8	7	3	II A
3687.66	4	4	2	.....	III	3832.50	2	5	4	tr	III A
3713.10	1	1	.....	.....	IV	3834.94	8	3	2	.....	III
3716.68	3n	1	.....	.....	IV	3836.22	4	2	1	.....	III
3730.96	10	10R	10r	8	I	3841.43	20	7	5	1	III
3732.19	12	12R	12r	8	I	3842.22	4n	2	.....	.....	IV

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3849.10	10	8	4	1	III	3963.85	30	12	9	5	II
3849.45	20n	8	3	.....	III	3969.22	5	5	4	tr	III
3849.60	8	10	7	6	I	3969.90	25	10	9	4	II
3850.20	20	12	4	1	III	3971.41	5	4	3	tr	III
3852.33	8	10	7	6	I	3972.83	2	2	1	.....	III
3853.30	3	2	1	.....	III	3976.44	1	1	.....	.....	IV
3854.36	12	8	3	.....	III	3976.85	25	20	12	4	II
3854.95	4n	1	.....	.....	IV	3978.80	4	5	3	.....	III
3855.41	5	3	2	.....	III	3979.95	3	4	2	.....	III
3855.73	8	5	3	.....	III	3981.41	5	6	3	.....	III
3856.41	5	3	2	.....	III	3984.08	20	12	8	4	II
3857.75	15	10	5	1	III	3984.50	10	8	5	1	III
3859.0	10n	6	3	.....	III	3990.14	6	3	tr	.....	IV
3862.69	3	1	.....	.....	IV	3991.30	20	12	8	4	II
3868.40	2	.....	.....	.....	V	3991.82	10	8	4	tr	III
3870.4	3n	2	1	.....	III	3992.29	1	1	.....	.....	IV
3874.70	10	5	3	.....	III	3992.99	15	10	4	.....	III
3875.3	4n	tr	.....	.....	IV	3994.13	4	4	2	.....	III
3879.39	8	5	2	.....	III	4000.12	2	.....	.....	.....	V
3881.41	5n	2	1	.....	III	4001.61	8	3	tr	.....	IV
3883.48	15	18r	15	10	I	4004.08	2	.....	.....	.....	V
3885.36	15	15r	12	8	I	4012.61	8	2	.....	.....	IV
3886.92	15	15r	12	8	I	4014.81	3	1	.....	.....	IV
3894.20	15	12r	10	7	I	4018.35	3	3	1	.....	III
3897.79	2	tr	.....	.....	IV	4022.40	8	2	.....	.....	IV
3902.24	2	.....	.....	.....	V	4023.90	2	.....	.....	.....	V
3903.05*	12	8?	6?	4?	II?	4025.18	7	6	3	tr	III
3903.29	8	8	7	5	I	4025.63	1	1	.....	.....	IV
3907.91	2	tr	.....	.....	IV	4026.31	10	10	5	1	III
3908.91	25	25R	15	10	II	4027.23	8	8	4	.....	III
3911.97*	10n	3	1	.....	III	4028.21	1	1	.....	.....	IV
3912.13*		4	2	.....	III	4033.44	3	3	2	.....	III
3915.98	6	5	2	.....	III	4037.42	3	3	2	.....	III
3916.41	12	10r	8	6	I	4039.20	10	4	1	.....	III
3917.19	2	1	tr	.....	III	4041.97	2	.....	.....	.....	V
3917.80	4	3	1	.....	III	4042.40	4	3	1	.....	III
3919.32	35r	35R	20r	12	II	4043.86	3	.....	.....	.....	V
3921.21	20	15r	12	9	I	4046.93	3	2	tr	.....	IV
3926.82	3	1	.....	.....	IV	4048.91	10	4	tr	.....	IV
3928.82	25	20r	15	10	I	4049.95	2	1	.....	.....	IV
3941.67	20	15r	12	10	I	4050.20	2	1	.....	.....	IV
3945.64	2	1	.....	.....	IV	4051.49	2	.....	.....	.....	V
3946.10	3	2	tr	.....	IV	4056.19	3	.....	.....	.....	V
3949.00	1	tr	.....	.....	IV	4056.95	2	.....	.....	.....	V
3949.71	2	1	.....	.....	IV	4058.94	10	4	tr	.....	IV
3951.26	3	2	tr	.....	IV	4060.82	2	.....	.....	.....	V
3951.93	2	1	tr	.....	III	4065.88	6	.....	.....	.....	V
3952.55	4	3	1	.....	III	4067.09	10	7	3	.....	III
3953.30	3	2	tr	.....	IV	4075.00	3	1	.....	.....	IV
3958.22	1	tr	.....	.....	IV	4076.20	4	1	.....	.....	IV
3960.91	1	1	tr	.....	III	4077.25	5	5	1	.....	IV

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.	
4077.85	4	1	.....	.....	IV
4081.90	3	2	.....	.....	IV
4085.20	2	1	.....	.....	IV
4090.50	3	1	.....	.....	IV
4092.35	3	1	.....	.....	IV
4097.80*		5	2	.....	III
4098.11*	20n	7	3	tr	III
4098.33*		7	3	tr	III
4099.19	4	2	tr	.....	IV
4101.33	4	2	tr	.....	IV
4104.01	2	1	.....	.....	IV
4105.00	6	3	1	.....	III
4106.22	2	.....	.....	.....	V
4108.56	3	2	1	.....	III
4109.73	8	4	2	.....	III
4111.02*		8	4	tr	III
4111.51*	20n	6	3	.....	III
4111.82*		3	1	.....	III
4120.78	8	5	2	.....	III
4121.45	4	.....	.....	.....	V
4121.98	7	4	1	.....	III
4122.35	5	3	1	.....	III
4123.54	10	6	1	.....	IV
4126.69	18	10	5	2	II
4127.10	3	3	1	.....	III
4127.46	4	1	.....	.....	IV
4127.81	5	5	2	.....	III
4128.56	3	.....	.....	.....	V
4129.36*	20n	10	5	tr	III
4131.55	10	2	.....	.....	IV
4134.55	3	.....	.....	.....	V
4146.38	4	tr	.....	.....	IV
4146.65	2	1	.....	.....	IV
4146.86	4	2	.....	.....	IV
4152.93	4	1	.....	.....	IV
4153.23	4	3	1	.....	III
4154.00	20	10	5	1	III
4161.55	12	1	.....	.....	IV
4163.79	20	4	1	.....	III
4165.70	10	1	.....	.....	IV
4170.00	6	2	.....	.....	IV
4170.40	4	1	.....	.....	IV
4171.86	3	3	1	.....	III
4172.95	4	1	.....	.....	IV
4174.36	1	1	.....	.....	IV
4174.53	1	1	.....	.....	IV
4175.01	15	15	5	1	III
4175.43	3	1	.....	.....	IV
4176.16	5	4	1	.....	IV
4178.12	3n	.....	.....	.....	V
4179.42	12	6	1	.....	IV
4183.25	1	1	.....	.....	IV
4185.10	3	4	1	.....	III
4185.53	2	2	.....	.....	IV
4186.51	3	1	.....	.....	IV
4190.31	3	1	.....	.....	IV
4191.45	10	8	3	1	II
4191.94	4	4	1	.....	III
4192.27	5	1	.....	.....	IV
4193.80	8	3	tr	.....	IV
4194.50	2	3	1	.....	III
4195.10	7	2	1	.....	III
4197.40	7	2	tr	.....	IV
4198.68	8	2	tr	.....	IV
4200.26	5	3	1	.....	III
4203.75	10	8	3	.....	III
4204.43	3	4	1	.....	III
4204.64	7	1	.....	.....	IV
4207.10	4	.....	.....	.....	V
4208.50	6	2	.....	.....	IV
4209.51	10	4	tr	.....	IV
4209.92	6	5	2	.....	III
4211.50*	6	5	1	.....	IV
4212.81	4n	1	.....	.....	IV
4213.36	4	3	tr	.....	IV
4216.52	8	6	1	.....	III
4217.75	15	10	3	.....	III
4221.73	8	2	.....	.....	IV
4222.90	6	6	2	.....	III
4224.68	4	.....	.....	.....	V
4230.68	4	4	1	.....	III
4232.41	3	2	tr	.....	IV
4233.05	2	2	.....	.....	IV
4234.70	3	3	1	.....	III
4237.90	2	2	tr	.....	IV
4239.12	8	7	2	.....	III
4240.89	10	8	2	.....	III
4243.01	1	1	.....	.....	IV
4248.45	2	2	tr	.....	IV
4248.87	2	1	.....	.....	IV
4252.39	2	1	tr	.....	III
4254.51	500R	1000 R	500R	250r	II
4255.70*	6	?	1	.....	III
4257.54	2	1	.....	.....	IV
4259.32	2	1	.....	.....	IV
4261.51	8	8	3	.....	III
4261.80	4	2	tr	.....	IV
4262.30	4	2	tr	.....	IV
4262.56	2	1	tr	.....	III
4263.30	12	5	1	.....	IV
4267.01	1	1	.....	.....	IV
4268.95	2	tr	.....	.....	IV

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.	
4270.15....	4	2	tr	.....	IV
4273.10....	6	2	1	.....	III
4275.00....	400R	800R	400R	200r	II
4280.57....	12	4	1	.....	III
4284.90....	2	3	1	.....	III
4289.90....	350R	700R	350R	175r	II
4292.14....	6	1	.....	.....	IV
4293.71....	4	3	1	.....	III
4295.91....	15	15	4	.....	III
4296.46....	1	tr	.....	.....	IV
4296.80....	1	tr	.....	.....	IV
4297.21....	5	5	2	.....	III
4297.89....	12	2	tr.	.....	IV
4299.85....	4	3	2	.....	III
4301.35....	6	2	tr	.....	IV
4305.61....	5	4	2	.....	III
4307.67....	1	tr	.....	.....	IV
4319.80....	8	6	2	.....	III
4320.78....	4	3	1	.....	III
4321.44....	3	2	tr	.....	IV
4321.81....	3	2	tr	.....	IV
4323.70....	5	1	.....	.....	IV
4325.25....	15	10	4	.....	III
4332.75....	2	1	.....	.....	IV
4337.74....	30	30R	25	20	I
4338.56....	3	1	.....	.....	IV
4338.95....	3n	1	.....	.....	IV
4339.62....	40	40R	30r	20	I
4339.90....	20	20r	20	12	I
4340.31....	8	8	3	.....	III
4343.33....	4	3	1	.....	III
4344.68....	40	40R	35r	25	I
4345.27....	2	2	.....	.....	IV
4346.99....	10	7	3	.....	III
4351.22....	20	20r	20	15	I
4351.98....	60	60R	40r	25	I
4354.13....	2	2	tr	.....	IV
4356.95....	4	3	1	.....	III
4357.69....	2	1	tr	.....	III
4359.82....	20	20r	20	20	I
4363.31....	6	6	3	.....	III
4368.45....	2	2	tr	.....	IV
4371.48....	20	20r	20	20	I
4373.42....	8	8	8	6	I
4373.81....	2	.....	.....	.....	V
4374.32....	12	8	4	1	II
4375.49....	8	5	2	.....	III
4376.95....	3	.....	.....	.....	V
4377.69....	4	3	1	.....	III
4381.30....	6	5	2	.....	III
4383.05....	2	2	1	.....	III
4385.15....	20	20r	20	20	I
4387.54H..	2	2	1	.....	III
4387.64H..	5	4	2	.....	III
4391.93....	8	8	8	6	I
4392.50....	1	1	.....	.....	IV
4393.74....	2	1	.....	.....	IV
4395.61....	2	1	.....	.....	IV
4397.44....	3	3	1	.....	III
4400.01....	3	3	1	.....	III
4403.55H..	3	3	1	.....	III
4403.68H..	5	1	tr	.....	IV
4406.46....	2	1	.....	.....	IV
4410.49....	4	4	1	.....	III
4411.15H..	2	1	tr	.....	III
4411.26H..	5	5	2	.....	III
4412.44....	6	10	10	6	I A
4414.02....	5	3	1	.....	III
4422.8.....	2	1	.....	.....	IV
4423.55....	3	4	1	.....	III
4424.20H..	2	2	1	.....	III
4424.49....	10	7	3	tr	III
4425.31....	3	1	.....	.....	IV
4428.66....	5	5	2	.....	III
4430.09....	2	1	.....	.....	IV
4430.72....	4	1	tr	.....	III
4432.35....	7	7	3	.....	III
4434.15....	2	2	1	.....	III
4442.45....	4	2	1	.....	III
4443.89....	4	1	.....	.....	IV
4450.5.....	3n	1	.....	.....	IV
4458.72....	12	10	4	tr	III
4459.57....	4n	4	1	.....	III
4459.92*...	6	?	?	?	?
4460.90....	4n	4	1	.....	III
4461.50....	1	tr	.....	.....	IV
4462.91....	3	3	1	.....	III
4464.85....	2	2	tr	.....	IV
4465.09....	4	4	1	.....	III
4465.31H..	2n	1	.....	.....	IV
4465.53....	5	5	2	.....	III
4466.35....	3	2	tr	.....	IV
4467.74....	4	3	1	.....	III
4468.55....	1	1	.....	.....	IV
4469.99....	1	1	.....	.....	IV
4473.96....	4n	4	2	.....	III
4475.50....	8n	8	3	.....	III
4477.20....	2n	4	2	.....	III A
4480.45*...	2	2	tr	.....	IV
	1	1	.....	.....	IV
4483.02....	5	3	1	.....	III
4488.21....	5	5	2	.....	III

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
4489.62....	5	2	tr	.....	IV	4595.79....	6	1	.....	.....	IV
4490.8*....	2n	1	.....	.....	IV	4600.30....	5	5	3	.....	III
4491.90....	3n	5	3	.....	III	4600.90....	20	20	20	20	I
4492.01....	3	2	1	.....	III	4601.21....	4	4	2	.....	III
4492.50....	6	3	2	.....	III	4613.53....	15	15	15	15	I
4495.50....	2	1	.....	.....	IV	4616.28....	25	25	25	25	I
4497.03....	25	25R	25r	25	I	4619.70....	8	5	2	.....	III
4498.87....	6	6	4	.....	III	4622.10....	10	10	4	.....	III
4500.42....	7	6	4	.....	III	4622.62....	5	3	1	.....	III
4501.25....	6	5	3	.....	III	4622.95....	3	2	tr	.....	IV
4501.90....	3	3	2	.....	III	4626.35....	20	20	20	20	I
4502.43....	1	1	.....	.....	IV	4632.39*...	2	?	.....	.....	IV?
4503.25....	2	1	.....	.....	IV	4633.49....	2	1	.....	.....	IV
4506.99....	4	1	.....	.....	IV	4637.36....	4	4	2	.....	III
4512.10....	10	8	3	.....	III	4637.95....	4	4	2	.....	III
4514.70....	8	6	2	.....	III	4639.78*...	2	?	.....	.....	IV?
4515.60....	4	3	1	.....	III	4646.35....	40	40	40	40	I
4521.32....	4	1	.....	.....	IV	4646.68*...	3	2	tr	.....	IV
4525.00....	2	.....	.....	.....	V	4646.99....	3	2	tr	.....	IV
4526.28....	3	2	.....	.....	IV	4648.29....	5	5	2	.....	III
4526.66....	15	12	10	3	II	4649.01....	5	3	tr	.....	IV
4527.53H*.	6	?	?	.....	III?	4649.61....	5	2	tr	.....	IV
4527.65H*.	4	?	?	.....	III?	4651.49....	20	20	20	20	I
4530.02....	5	5	2	.....	III	4652.38....	30	30	30	30	I
4530.91....	20	15	10	3	II	4654.94....	3	2	tr	.....	IV
4535.33....	6	6	3	.....	III	4656.38*...	2	?	.....	.....	IV?
4535.89*...	15	8?	6?	2	II	4663.53....	7	3	tr	.....	IV
4539.94....	5	5	3	.....	III	4664.05....	8	4	1	.....	III
4540.64....	12	8	5	2	II	4665.00....	8	5	2	.....	III
4540.88....	10	6	3	.....	III	4666.10....	4	1	.....	.....	IV
4541.23....	5	4	3	.....	III	4666.40....	4	3	1	.....	III
4541.65....	4	2	1	.....	III	4666.72....	7	3	1	.....	III
4542.76....	5	3	1	.....	III	4667.34....	2	1	.....	.....	IV
4543.89....	2	2	1	.....	III	4669.52....	6	3	1	.....	III
4544.78....	12	10	6	2	II	4680.70....	4	2	1	.....	III
4545.47....	5	5	3	.....	III	4681.10*...	3	?	?	.....	IV?
4546.10....	20	20	20	20	I	4689.55....	8	6	2	.....	III
4555.01....	2	2	.....	.....	IV	4694.15....	5	3	1	.....	III
4555.30....	1	1	.....	.....	IV	4695.35*...	3	?	1?	.....	III?
4556.35....	6	3	1	.....	III	4697.25....	5	4	2	.....	III
4563.89....	2	2	tr	.....	IV	4698.71....	20	12	5	1	III
4564.36....	3	.....	.....	.....	V	4700.80....	4	3	tr	.....	IV
4565.70....	12	12	12	12	I	4706.29....	2	1	.....	.....	IV
4569.80....	8	6	2	.....	III	4708.20....	15	6	3	tr	III
4571.28....	1	1	.....	.....	IV	4718.63....	20	8	4	1	III
4571.89....	10	8	4	.....	III	4723.31....	4	3	1	.....	III
4575.30....	2	1	.....	.....	IV	4724.60....	4	3	1	.....	III
4580.26....	20	20	20	20	I	4727.32....	6	4	1	.....	III
4584.30....	2	1	.....	.....	IV	4729.92....	2	1	.....	.....	IV
4586.31....	2	1	.....	.....	IV	4730.90....	8	6	3	.....	III
4591.61....	20	20	20	20	I	4737.52....	10	6	3	.....	III

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.	
4745.49....	2	3	1	.....	III
4752.29....	6	2	tr	.....	IV
4754.92....	2	2	tr	.....	IV
4755.33....	2	2	tr	.....	IV
4756.30....	15	10	6	1	III
4764.48....	5	3	1	.....	III
4764.87....	1	1	tr	.....	III
4766.88....	2	1	tr	.....	III
4767.47....	1	tr	.....	.....	IV
4768.02....	3	2	tr	.....	IV
4775.32....	1	1	.....	.....	IV
4789.53....	20	12	8	3	II
4790.55....	2	4	2	.....	III A
4792.72....	15	8	3	.....	III
4796.33....	2	1	.....	.....	IV
4801.24....	15	9	4	.....	III
4806.48....	1	3	1	.....	III A
4810.95....	1	2	tr	.....	III A
4814.50....	1	2	tr	.....	III A
4829.53....	18	15	9	2	II
4837.06....	2	2	1	.....	III
4846.52....	1	1	.....	.....	IV
4861.40....	4	4	2	.....	III
4862.01....	15	12	6	1	III
4870.99....	20	10	4	1	III
4874.82....	1	1	.....	.....	IV
4880.21....	1	1	.....	.....	IV
4885.13....	1	3	1	.....	III A
4885.92H..	4	5	3	.....	III
4886.11H..	1	2	tr	.....	IV A
4887.20....	20	6	4	1	II
4887.88....	1	1	tr	.....	III
4888.71....	4	4	2	.....	III
4903.47....	8	6	3	.....	III
4921.15....	3	2	tr	.....	IV
4922.49....	20	10	6	1	III
4936.50....	10	5	2	.....	III
4942.68....	8	30	20	10	II A
4954.99....	10	5	2	.....	III
4965.10....	6	20	15	8	II A
5013.49....	6	5	2	.....	III
5022.04....	2	10	7	4	II A
5048.95....	2	8	6	3	II A
5052.08....	8	10	8	6	I
5066.06....	5	2	1	.....	III
5067.87....	10	3	1	.....	III
5068.45....	2	8	6	3	II A
5073.10....	12	10	8	6	I
5092.03....	3	8	6	3	II A
5110.93*...	7	3	2 ?	1 ?	II ?
5113.30*...	5	3	?	1 ?	II ?
5122.27....	4	5	4	3	I
5123.63....	6	8	6	4	I
5139.81....	12	2	.....	.....	IV
5144.85*...	7	?	?	1	II ?
5161.94*...	3	?	?	.....	III ?
5166.41....	15	3	1	.....	III
5177.57....	7	2	tr	.....	IV
5184.73....	10	3	1	.....	III
5192.18....	10	3	1	.....	III
5193.67....	4	1	.....	.....	IV
5196.61....	15	4	1	.....	III
5200.37....	6	2	tr	.....	IV
5204.71....	150r	120R	70R	50	II
5206.24....	200r	150R	80R	60	II
5208.60....	300r	200R	100R	75	II
5212.40....	3	1	.....	.....	IV
5214.27....	6	2	tr	.....	IV
5221.10....	3	1	.....	.....	IV
5221.93....	8	3	1	.....	III
5222.85....	2	2	tr	.....	IV
5224.24....	3	1	.....	.....	IV
5224.70....	3	1	.....	.....	IV
5225.19....	25	10	3	tr	III
5226.00....	4	3	1	.....	III
5227.09....	4	2	.....	.....	IV
5228.25....	3	1	.....	.....	IV
5230.35....	2	2	1	.....	III
5239.12....	5	5	2	tr	III
5240.62....	3	1	.....	.....	IV
5241.62H..	1	1	.....	.....	IV
5243.53....	7	3	1	.....	III
5247.72....	40	20r	20	20	I
5255.08H..	10	4	tr	.....	IV
5255.27H..	15	6	1	.....	IV
5261.91....	6	2	.....	.....	IV
5264.35....	50	30R	30	20	I
5265.33....	8	4	1	.....	III
5265.90....	25	20r	20	12	I
5272.18....	8	4	1	.....	III
5273.59....	6	2	1	.....	III
5275.33....	20n	12	4	2	II
5275.85H..	15n	12	6	3	II
5276.20H..	20n	12	6	3	II
5278.39....	2	.....	.....	.....	V
5280.48....	4	2	.....	.....	IV
5287.34....	4	2	.....	.....	IV
5296.86....	50	25r	25	20	I
5297.48....	20n	12	8	3	II
5298.14H..	15n	10	6	2	II
5298.46....	60	30r	30	25	I
5300.89....	25	15	15	12	I

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace High Temp.	Furnace Medium Temp.	Furnace Low Temp.	Class	λ (Exner and Haschek)	Arc	Furnace High Temp.	Furnace Medium Temp.	Furnace Low Temp.	Class
5304.33....	4	1	.....	.....	IV	5720.03....	2	2	1	.....	III
5313.02....	5	2	tr	.....	IV	5729.41....	1	1	.....	.....	IV
5318.92....	4	2	.....	.....	IV	5738.75....	1	1	tr	.....	III
5328.53....	50n	15	10	6	II	5746.64....	2	1	tr	.....	III
5329.33....	20n	10	6	3	II	5753.89....	2	.....	.....	.....	V
5329.95....	5n	4	2	1	II	5781.42....	8	5	3	tr	III
5340.65*...	4	?	.....	.....	IV?	5782.10....	8	5	3	tr	III
5345.00....	2	2	1	.....	III	5783.38....	20	10	5	1	III
5345.99....	70	40R	40	30	I	5784.17....	20	10	5	1	III
5348.50....	50	30R	30	20	I	5785.29....	20	8	4	1	III
5387.14....	5	2	tr	.....	IV	5785.95*...	15	6	4	1	III
5387.73*...	3	?	tr	.....	III	5786.19*...	?	10	10	5	I A
5390.60....	3	1	.....	.....	IV	5787.25....	3	3	2	.....	III
5391.56....	2	?	.....	.....	IV	5788.22....	40	12	8	2	III
5400.75....	8	3	1	.....	III	5788.59....	4	2	1	.....	III
5405.19....	3	?	.....	.....	IV	5791.30....	50	20	15	3	III
5410.01....	100	60R	60	40	I	5792.00....	1	1	tr	.....	III
5442.60....	3	?	.....	.....	IV	5838.88....	2	2	1	.....	III
5464.12....	4	?	.....	.....	IV	5844.84....	2	2	1	.....	III
5480.71....	4	2	.....	.....	IV	6330.30....	25	50	50	50	I A
5628.82....	8	4	2	.....	III	6363.03....	15	30	30	30	I A
5638.37....	1	1	tr	.....	III	6501.43....	2	15	10	10	I A
5642.59....	2	2	1	.....	III	6529.36....	2	.....	.....	.....	V
5648.40....	1	1	tr	.....	III	6538.12....	3	18	15	15	I A
5649.52....	2	2	tr	.....	IV	6573.10....	2	12	12	12	I A
5658.82....	1	1	tr	.....	III	6597.80....	2	.....	.....	.....	V
5664.24....	8	4	2	.....	III	6630.25....	4	20	20	20	I A
5681.42....	2n	.....	.....	.....	V	6661.30....	12	3	.....	.....	IV
5682.63....	4n	2	1	.....	III	6669.50....	3	1	.....	.....	IV
5694.94....	10	4	2	.....	III	6881.7.....	2	1	tr	.....	III
5698.53....	20	6	3	tr	III	6882.4.....	5	2	1	.....	III
5700.75....	1	1	tr	.....	III	6883.2.....	10	4	2	.....	III
5702.52....	10	5	2	.....	III	6924.4.....	10	5	2	.....	III
5712.87....	2	.....	.....	.....	V	6925.4.....	6	3	1	.....	III
5712.98....	6	7	3	tr	III	6978.75....	15	8	2	.....	III

REMARKS ON TABLE II

λ	
3578.81, 3593.64, 3605.49	Widely reversed at high temperature.
3603.89	Concealed at high temperature by λ 3605.49.
3903.05	Difficult blend with Class II Fe line.
3911.97, 3912.13	Measured by writer in vacuum arc. Blend into wide and diffuse line in arc in air.

λ	
4097.80	As for λ 3912.
4098.11	
4098.33	
4111.02	As for λ 3912.
4111.51	
4111.82	
4129.36	Measured by writer in vacuum arc.
4211.50	May be close double.
4255.70	Concealed at high temperature by λ 4254.51.
4459.92	Blend with strong V line in furnace.
4480.45	Double, scarcely resolved.
4490.8	Very diffuse in arc.
4527.53	Blend with strong Ti line in furnace.
4527.65	
4535.89	Blend with Ti.
4632.39	Disturbed by carbon.
4639.78	Disturbed by carbon.
4646.68	λ Rowland.
4656.38	Disturbed by carbon.
4681.10	Disturbed by carbon.
4695.35	Disturbed by carbon.
5110.93	Disturbed by carbon.
5113.30	
5144.85	Disturbed by carbon.
5161.94	
5340.65	Disturbed by carbon.
5387.73	
5785.95	λ Rowland.
5786.19	λ Rowland. Faint in arc, blended with λ 5785.95.

GENERAL CHARACTERISTICS OF THE VANADIUM AND CHROMIUM SPECTRA

1. *Low temperature lines of chromium.*—As has been noted, some chromium lines appeared at a temperature lower than that used for the low-temperature column of Table II. Table III is a list of these lines with their intensities estimated from a photograph taken with the 1-meter concave grating, a bathed film with filter being used so that the spectrum from λ 3500 into the red was registered. The temperature read 1728° C. and the prolonged exposure made it probable that the spectrum for this temperature was fairly complete. Almost all of the lines as far as λ 5000 were

obtained also on a plate taken at the same temperature with the 15-foot concave grating.

The intensities in Table III are quite different from those in the low-temperature column of Table II, given at 2000–2100°. This is probably in some measure due to differences in contrast and color-curve between the film and the plate, but chiefly to the fact that the lines of Class I retain a high relative intensity at the minimum temperature for their appearance, while those of Class II, which make up the remainder of Table III, are weaker than in Table II.

TABLE III

CHROMIUM LINES GIVEN BY A TEMPERATURE OF 1700–1800°

λ	I	λ	I	λ	I
3578.81	25	4344.68	40	5048.95	tr
3593.64	20	4351.22	20	5052.08	3
3605.49	20	4351.98	30	5068.45	1
3615.77	1	4359.82	40	5073.10	5
3730.96	3	4371.48	50	5092.03	1
3732.19	3	4373.42	10	5122.27	1
3883.48	8	4385.15	40	5123.63	2
3885.36	7	4391.93	8	5204.71	70
3886.92	7	4412.44	4	5206.24	80
3894.20	6	4497.03	60	5208.60	100
3903 {.05, .29}	10	4546.10	60	5247.72	50
		4565.70	25	5264.35	50
3908.91	10	4580.26	50	5265.90	30
3916.41	6	4591.61	35	5296.86	60
3919.32	12	4600.90	50	5298.46	60
3921.21	8	4613.53	40	5300.89	20
3928.82	8	4616.28	50	5328.53	1
3941.67	12	4626.35	50	5329.30	tr
4254.51	200	4646.35	60	5345.99	80
4275.00	175	4651.49	40	5348.50	70
4289.90	150	4652.38	50	5410.01	80
4337.74	30	4942.68	10	6330.30	12
4339.62	20	4965.10	6	6363.03	6
4339.90	20	5022.04	tr	6630.25	3

2. *Successive development of the classes.*—The low-temperature spectrum, described for chromium in the preceding section, occurs for each of the elements which have been studied with the furnace at a stage probably not more than 200° above the melting-point. The medium temperature (about 2300°) produces a rich spectrum. The Class II lines are well developed and the Class III lines are present. Those lacking are the weaker arc lines, some lines which

are strong but diffuse in the arc, and the enhanced lines. At the highest temperatures used the number is increased by the addition of the Class IV lines, and in the case of vanadium, as with titanium, by the faint appearance of some of the stronger enhanced lines. A striking change produced by the high temperature is the general widening of the lines present at lower temperature, together with an increase in the number of reversals.

3. *Changes with the wave-length.*—Photographs made with the 1-meter concave grating showed the spectra of vanadium and chromium extending farther into the ultra-violet as the temperature rises, a condition also observed for iron and titanium. The limits of the vanadium spectrum on these films are roughly λ 3200, λ 2800, and λ 2500 for the three temperatures. The arc spectrum extends to shorter wave-length. Aside from the extension toward shorter waves nothing definite appears in the way of a general change. Low-temperature lines occur in groups throughout the spectrum, beginning with the limit in the ultra-violet. At the red end, while a number of lines occur in each spectrum for which the furnace is more favorable than the arc, these are not relatively strong at low temperature, but are for the most part in Class III.

The tendency in all light-sources for lines of shorter wave-length to reverse more easily is perhaps nowhere so striking as in the furnace spectra. If reversal were dependent merely on the presence of rarer vapor at a lower temperature, lines in the red region should reverse as easily as in the violet, since a number of red lines are given by the low-temperature furnace. Reversal is, however, clearly a function of wave-length. The high-temperature furnace gives numerous and wide reversals of lines in the region of shorter wave-length, presumably by reason of the cooler vapor near the ends of the tube; but in the green reversal becomes more difficult and in the yellow and red even the strong low-temperature lines of these elements remain hard and sharp in the furnace spectrum.

4. *Absence of the band spectra.*—The arc spectra of vanadium and chromium each show a series of bands shaded toward the red. The heads of these have been measured[1] as approximately λλ 5470, 5737,

[1] Kayser, *Handbuch der Spectroscopie*, **5**, 376; **6**, 786.

6087, 6478 for vanadium, and λλ 5565, 5795, 6052, 6395 for chromium. These appear distinctly on my arc photographs but in none of the furnace spectra. The present evidence is that these bands are due to oxides formed in the arc and are not low-temperature spectra of the metals themselves.

5. *Comparison with the arc spectrum.*—In Tables I and II lines of intensity 1 in the arc are entered only when they occur also in the high-temperature furnace. The number of arc lines in Exner and Haschek's tables which are thus omitted from the furnace list is much greater for chromium than for vanadium. Of the stronger arc lines 35 chromium lines occur in Class V, while this class for vanadium is limited almost entirely to the enhanced lines (*V E*). In short, the relative behavior of the two elements is similar to that of titanium and iron, in that when the vanadium spectrum has once appeared (its high melting-point rendering the initial temperature higher than that of chromium), the furnace is highly efficient in producing a rich spectrum, giving at high temperature a spectrum closely comparable in number of lines with that of the arc.

The most interesting difference between the arc and furnace spectra is probably the large number of lines relatively much stronger in the furnace than in the arc and designated by *A* after the class number. It is difficult to reconcile the behavior of these lines with a continuous change in temperature alone between the arc and the furnace. It would appear that certain conditions needed for the emission of these lines are stronger in the furnace than in the arc. No discontinuity is apparent in the development of the spectrum from one furnace temperature to another. A line strong at low temperature is strong also at medium and high temperatures, but it may be a weak line in the arc, and the same is true for lines which develop at the successive temperature stages. A Class III line, for example, may show a normal increase from medium to high temperature and then drop to a low intensity in the arc. Further investigation may show that the emission of such lines is greatly localized in the arc and that the furnace is better suited to produce a vapor in the same condition as the given region of the arc, but at present the reason for the difference is obscure.

EXPLANATION OF THE PLATES

The two sections of Plate II show the vanadium spectrum from λ 4000 to λ 4950 for the arc and for three furnace temperatures. An interesting region in the red is reproduced in Plate III. The large changes in relative intensity of many lines are brought out, together with the maintenance of a high intensity at low temperature by the lines of Class I. The development of a typical carbon fluting is well shown in Plate II. The low temperature is barely able to produce the strong head at λ 4737.

Plate IV gives a similar series of arc and furnace spectra for chromium from λ 5100 to λ 5425. Most of the prominent lines here belong to Class I and the chief change in them is a widening at high temperature. Strong lines in other classes occur, however, at λλ 5197, 5225, 5255, and the groups at λλ 5276 and 5329. The growth of the strong carbon band λ 5165 is also shown in this plate.

SUMMARY

1. The electric furnace spectra of vanadium and chromium have been studied for the ranges λ 3150–λ 6850 and λ 3550–λ 7000, respectively, the classification of lines being based on a comparison of the spectra given by three furnace temperatures with reference to the temperature at which a line appears and its rate of strengthening with increase of temperature.

2. The leading features in the development of the vanadium and chromium spectra are similar to those observed for iron and titanium, the vanadium spectrum being very similar to the latter.

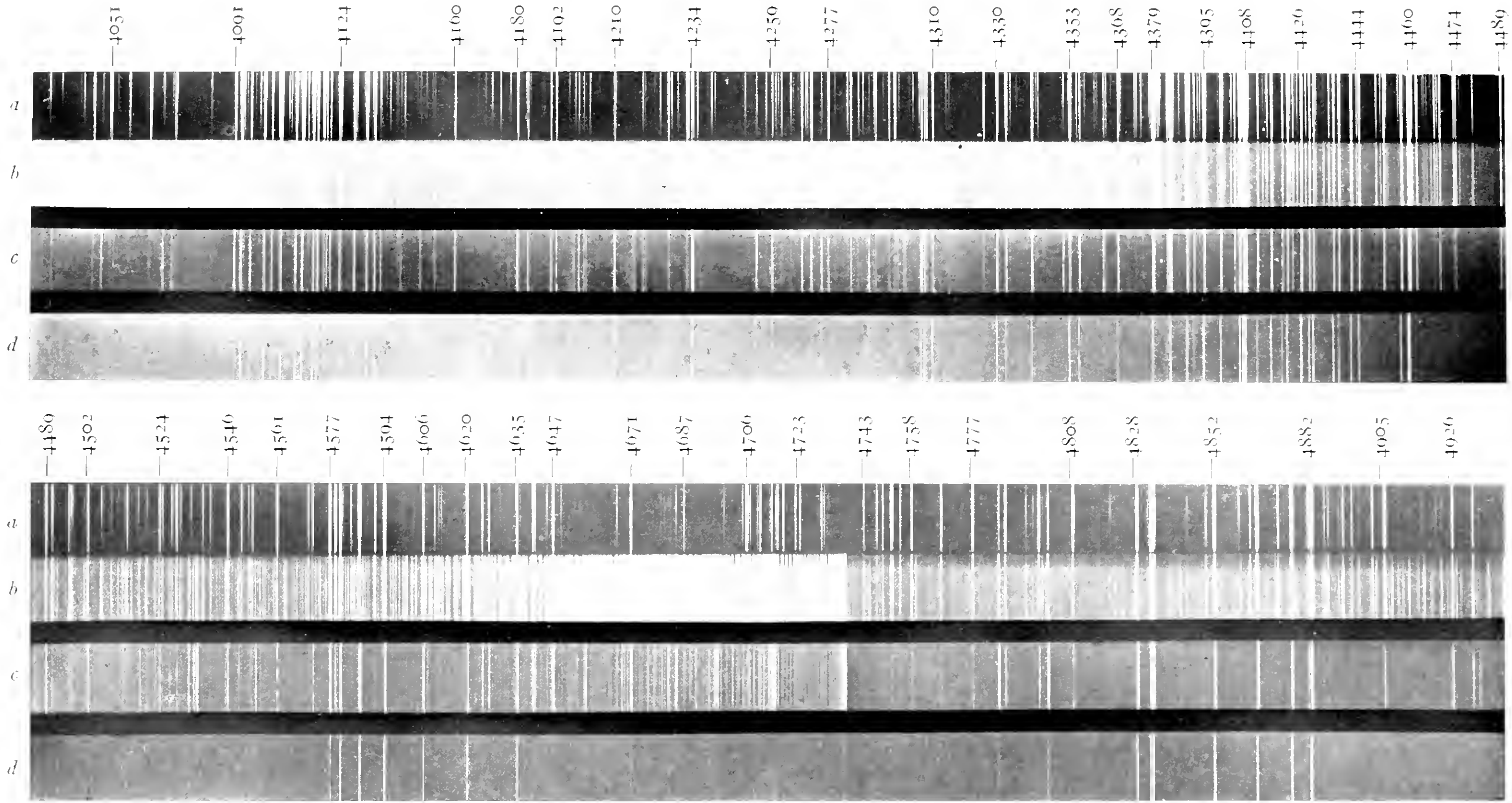
3. The chromium spectrum near the temperature at which the vapor begins to radiate shows a predominance of the lines of Class I, which change little at higher temperatures.

4. Certain chromium lines, very diffuse in the arc in air, may be resolved into sharp components in a vacuum source, either furnace or arc.

5. A large number of lines belonging to various furnace classes are relatively weak in the arc.

6. The extension of the spectrum into the ultra-violet increases as the temperature rises. In other respects the distribution of

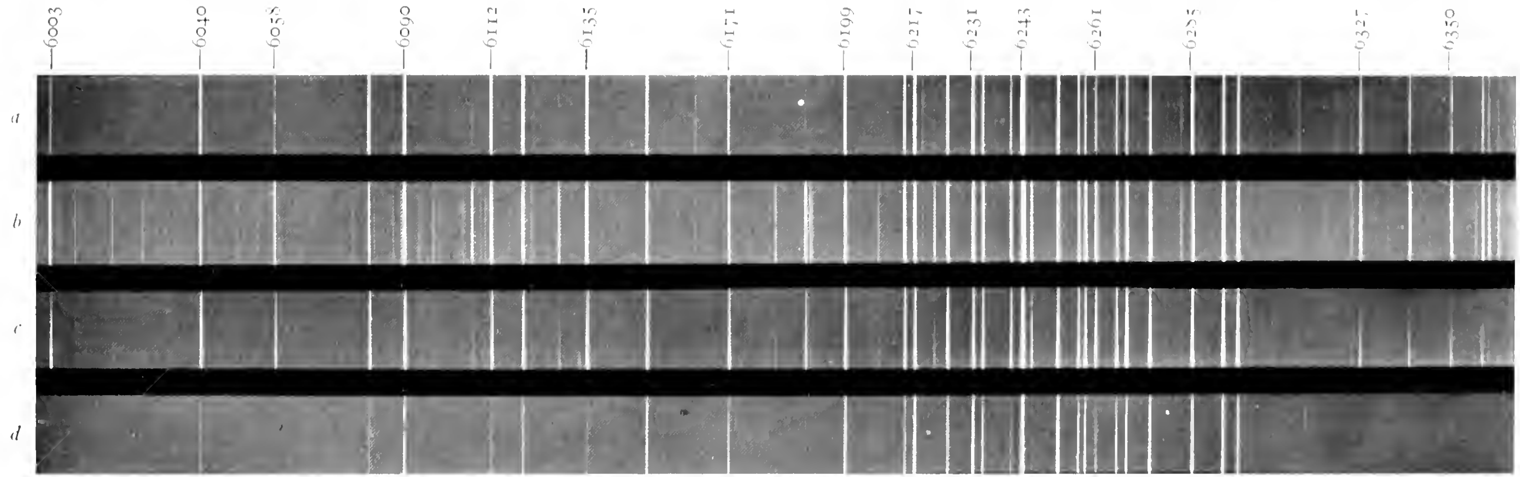
PLATE II



FURNACE AND ARC SPECTRA OF VANADIUM

a. Vanadium in carbon arc.
b. Spectrum of the electric furnace at 2000° C.
c. Spectrum of the electric furnace at 2350° C.
d. Spectrum of the electric furnace at 2100° C.

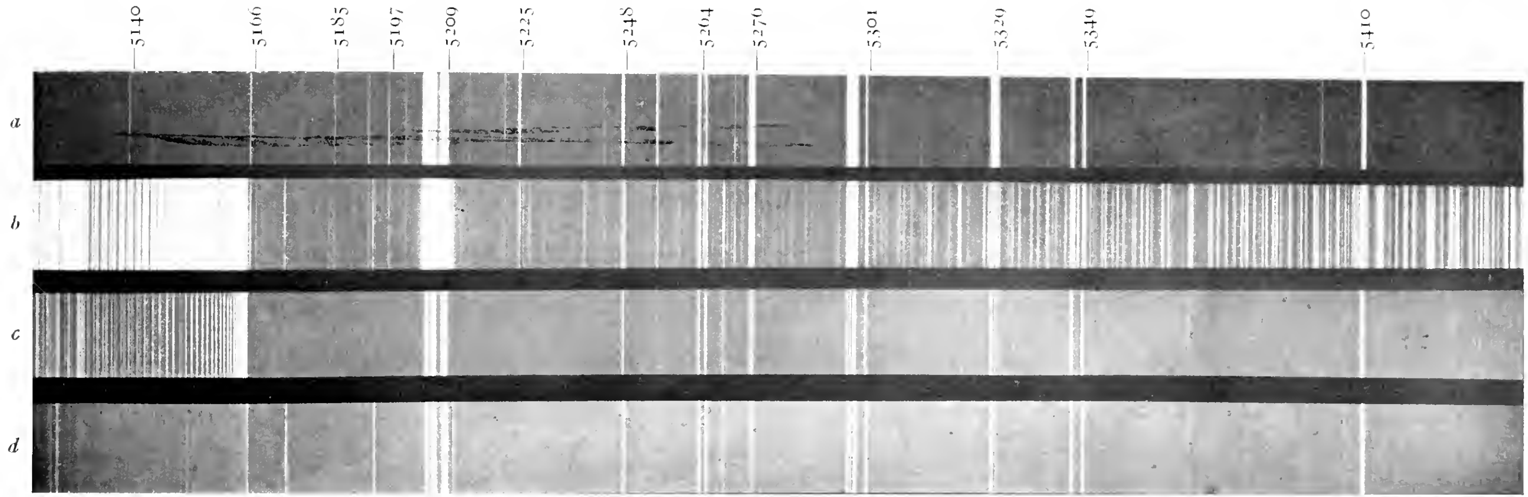
PLATE III



FURNACE AND ARC SPECTRA OF VANADIUM

a. Vanadium in carbon arc.
b. Spectrum of the electric furnace at 2600° C.
c. Spectrum of the electric furnace at 2350° C.
d. Spectrum of the electric furnace at 2150° C.

PLATE IV



FURNACE AND ARC SPECTRA OF CHROMIUM

a. Arc spectrum of chromium.
b. Spectrum of the electric furnace at 2000° C.
c. Spectrum of the electric furnace at 2350° C.
d. Spectrum of the electric furnace at 2100° C.

lines at different temperatures shows no definite relation to the wave-length.

7. The ability of lines to show self-reversal in the furnace distinctly increases with decreasing wave-length.

8. The absence from the furnace of the banded spectra which appear in the vanadium and chromium arcs indicates that they are probably due to oxides of the metals.

Mount Wilson Solar Observatory
November 1914

THE FLASH SPECTRUM WITHOUT AN ECLIPSE REGION λ 4800–λ 6600[1]

By WALTER S. ADAMS and CORA G. BURWELL

In a brief communication[2] published in 1909 Hale and Adams described the methods employed in photographing the chromospheric spectrum with the 60-foot tower telescope and the powerful spectrograph used in conjunction with it. Some results of the observations in two limited regions of the spectrum were given to indicate the character of the photographs obtained and the degree of accuracy of the measured wave-lengths. Observations made since that time by Mr. Hale with the 150-foot tower telescope have shown that the use of the larger solar image probably will lead to a distinct advance in the quality of the chromospheric photographs. In spite of this consideration, however, it has seemed desirable to publish the results already obtained, not only because they give some indication of the possibilities in the way of investigations of the chromospheric spectrum with the use of a solar image of moderate size, but also because the results almost certainly will differ to some extent from those obtained with the larger image on account of difference in the level of the observations. Since the slit is held rigorously tangent to the solar image during the exposures, it should be possible under the finest conditions of definition to reach a somewhat lower level in the chromosphere with the larger image.

The method employed in obtaining the photographs was that described in the communication by Hale and Adams already referred to. The light from the sun's limb falls upon a diagonal prism so placed as to reflect the light horizontally to a second prism immediately above the slit. The first prism is mounted upon a slide with a screw adjustment allowing of motion toward or away from the second prism. After the sun's image has been brought tangent to the slit the observer selects a bright line of the chromospheric spectrum and brings it into the field of view of an

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 95.

[2] *Mt. Wilson Contr.*, No. 41; *Astrophysical Journal*, **30**, 222, 1909.

eyepiece, mounted in an opening near the end of the plate-holder. During the exposure this line is maintained at maximum brightness by guiding with the screw controlling the position of the first diagonal prism, thus moving the sun's image slightly on the slit. The objective employed in the 60-foot tower telescope is corrected for visual light and hence is not well adapted for photography in the blue and violet portions of the spectrum. For this reason, and on account of the difficulty of seeing with sufficient distinctness in this region the bright lines necessary for guiding, only a very few photographs have been obtained to the violet of λ 4800.

The second order of the grating was used for all of the photographs, corresponding to a linear scale on the negatives of about 1 mm = 0.9 angstrom.

The exposure times varied from four minutes in the yellow and green region to eight minutes in the red.

Table I contains the results of the measures. The portion of the spectrum between λ 4800 and λ 5500 has been studied much more extensively than that to the red of λ 5500, and the wave-lengths given depend upon a larger number of determinations. For lines of greater wave-length than λ 5900 only two measures are available.

The photographs upon which these results are based were taken largely to test the methods employed, and in the case of some of the earlier photographs the diagonal prisms used were too small to give the full length of the brightest and longest chromospheric lines. As a result we have not attempted to measure the lengths of the lines and use them as a basis for discussion of level in the solar atmosphere. It is evident, however, that with a slit of sufficient length to admit the longest lines, measures of the size of the arcs made in this way would have a marked advantage over those from eclipse photographs taken without a slit in that the exposure times would be uniform for lines of all lengths and not progressively longer as in eclipse spectra for the lines of greatest length. The photographs taken without an eclipse have, moreover, the advantage of accurate guiding.

The results given in Table I are for the most part self-explanatory. The measured wave-lengths of the bright lines are in the first column, and following these the lines in Rowland's

table with the corresponding elements and intensities. We have preferred not to add a large number of somewhat questionable identifications to those made by Rowland, but have included several taken mainly from Hasselberg's arc tables which sun-spot observations have verified. The chromospheric intensity given in the fifth column is on an arbitrary scale extending from 0, a line just visible on the continuous background, to 50, which is the intensity of D_3 on our photographs.

The abbreviations used in the last column are as follows:

dr = double reversal
w = wide
bf = bright fringes
E = enhanced line

The term "bright fringes" is used in the case of dark lines which show a faint bright line on either side, in general too weak for measurement. They are true double reversals but very faint. These lines, on which no measurements have been made, are indicated in the first column of the table by the absence of figures beyond the decimal point, these being given in the second column (from Rowland's table).

THE LEVEL OF THE OBSERVATIONS

There are three features in these results that indicate a very low level in the solar atmosphere for the point under observation.

1. Essentially all of the stronger lines are double reversals, similar in type to those of the hydrogen lines, but of course very much narrower. This is an indication of low level.

2. A large proportion of the bright lines are very faint absorption lines in the solar spectrum. St. John has shown clearly that in general the fainter the line the lower the level of the gas producing the absorption.

3. The carbon fluting with its head at λ 5165 is very strong. This fluting is known from visual observations to originate at a very low level in the solar atmosphere.

In view of these facts, quite apart from the obvious consideration that a slit tangent to a solar image 16.8 cm in diameter under good conditions of definition should reach a point very close to the

TABLE I

Wave-Lengths and Intensities for Chromosphere Lines

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
4802.888	.879	....	0000	1	
4804.220	.232	La	000	1	
4804.530	.706	Co?	0	0	dr
.892				0	
4805.301	.285	Ti	3	2	dr E
4805.605	.606	Ti	0	1	
4807.308	......	....	....	0	
4807.726	.725	Cr, V	000	1	
4807.	.900	Fe	1	.....	bf
4809.204	......	La	....	2	
4810.730	.724	Zn	3	1	
4811.532	.542	Nd	000	2	
4813.670	.661	Co	1	2	
4814.147	.166	....	000N	1	
4814.676	......	....	....	0	
4815.262	.239	....	0000	0	
4815.831	.820	....	0000	0	
4816.011	.013	....	0000	1	
4817.856	.988	Ni? Fe?	2	0	dr
4818.033				0	
4819.173	.205	....	0000	0	
4819.818	.830	Y	0000	0	
4820.514	.593	Ti	1	1	
4823.543	.697	Mn	5	1	dr
.856				0	
4824.230	.325	Fe, Cr	3	1	dr E
.484				0	
4825.664	.666	Ti	000	3	
4825.906	.907	....	000	0	
4827.917	......	....	....	0	
4828.729	......	....	....	1	
4831.710	......	....	....	0	
4832.466	.460	Nd	0000	1	
4834.548	.695	Fe	1	0	dr
.834				0	
4835.890	6.059	Fe	2	1	dr
6.217				1	
4836.310	.313	Ti	0000	0	
4836.935	7.044	Cr	00	0	dr
7.180				0	
4838.543	.699	....	2	2	dr
.957	.837	Fe, Ni	1	1	
4839.594	.734	Fe	3	0	dr
.869				0	
4840.197	.193	....	0000	c	
4840.431	.449	Co	2	1	
4840.925	1.074	Ti	3	0	dr
1.250				0	
4843.	.336	Fe	3	.....	bf
4844.401	.408	Mn	0000	1	w
4846.766	......	....	....	0	
4848.121	.110	....	0000	0	
4848.282	.438	Cr	2	0	dr E
.729	.605	Ti	0000	0	
4849.242	.357	....	0	1	dr
.453				0	
4849.664	.845	Cr	00	0	dr
50.073				0	
4851.680	.689	Ca, V	1	1	w
4852.	.743	....	2	.....	bf
4854.584	.535	....	0000	0	
4855.030	.059	Fe, Y	1	4	
4855.	.600	Ni	3	.....	bf
4856.195	.203	Ti	1	0	
4857.	.579	Ni	1	.....	bf
4859.204	.221	Nd	000	1	
4859.803	.928	Fe	4	0	dr
60.050				0	
4861.092	.527	H, La	30	20	dr
.898				15	
4862.621	.783	....	0	0	dr
.923				0	
4864.356	.362	....	0000	0	
4864.484	.505	Cr	1	0	E
4864.906	.919	V	0	0	
4865.793	.798	....	1	0	
4866.331	.465	Ni	2	0	dr
.593				0	
4866.906	.930	....	0000	0	
4867.585	.724	....	00	0	dr
.847				0	
4868.048	.056	Co	1	2	
4868.252	.451	Ti	0	1	dr
.442				(2)	
.709				1	
4870.316	.323	Ti	1	1	
4870.982	.996	Ni, Cr	3	0	
4871.	.512	Fe	5	.....	bf
4872.	.332	Fe	4	.....	bf
4873.639	.630	Ni	2	0	
4874.189	.196	Ti	0	1	E
4874.368	.379	....	0000	0	
4874.689	.693	....	0000	1	w
4875.668	.671	V	1	1	
4876.	.586	Cr	1	.....	bf E
4878.169	.313	Ca	3	1	dr
.548	.407	Fe	4	1	
4881.750	.739	V	1N	1	
4882.	.336	Fe	3	.....	bf
4882.650	.670	Ce	000	1	

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
4883.798	.867	Y	2	2	dr
.876				(4)	
.942				2	
4885.106	.264	Ti	2	0	dr
.421				1	
4885.	.620	Fe	3	.....	bf
4886.094	.132	Cr	00	0	
4887.182	.187	Ni, Cr	2	1	
4887.729	.715	....	0000	0	
4889.	.187	Fe?	3	.....	bf
	.294	Fe	2	.....	
4890.	.948	Fe	6	.....	bf
4891.	.683	Fe	8	.....	bf
4892.012	.047	Ti	000	1	
4893.	.030	Fe	1	.....	bf
4893.182	.228	Ti, Sc	000	0	
4893.987	.997	....	00	1	
4894.142	.141	Ce	0000	0	
4896.	.625	Fe	1	.....	bf
4900.102	.095	Ti, La	2	1	
4900.300	.301	Y	2	3	
4900.814	.808	....	000	0	w
4901.056	.152	Ti	0	0	dr
.270				0	
4902.248	.257	....	0000	0	
4903.	.502	Fe	5	.....	bf
4903.909	.896	....	0000	0	
4904.403	.597	....	3	0	dr
.761				0	
4905.143	.310	Fe?	0	0	dr
.487				0	
4908.032	.209	....	0N	0	dr
.325				0	
4908.628	.673	Co	000	0	
4909.439	.566	Fe	2	0	dr
.703				0	
4910.	.505	Fe	2	.....	bf
4910.965	.952	....	000N	0	
4911.387	.374	Ti	1	1	E
4912.226	.199	Ni	1	0	
4913.424	.450	....	0000	0	
4913.810	.803	Ti	2	1	
4914.175	.150	Ni	2	0	
4914.560	.583	Nd	0000	2	
4917.023	.028	....	0000	0	
4917.	.410	Fe	2	.....	bf
4918.536	.543	Ni, Ti	2	1	
4918.884	.886	Ni	0	1	
4919.019	.174	Fe	6	0	dr
.324				0	
4920.044	.047	....	00	2	
4920.220	.241	....	0000	0	
4920.552	.685	Fe	10	0	dr
.851				1	
4921.158	.147	La	0	3	
4921.982	.963	La, Ti	1	4	He?
4922.449	.446	Cr	2	0	
4923.544	.540	....	000d	0	
4924.012	.107	Fe	5	5	dr E
.189				4	
4924.	.956	Fe	3	.....	bf
4925.573	.746	Ni, V	1	0	dr
.876				1	
4926.034	.....	....	....	0	
4928.	.050	Fe	2	.....	bf
4928.513	.511	Ti, Co	0	2	
4933.300	.514	Fe	2	0	dr
.711				0	
4934.152	.214	Ba-Fe?	3	1	dr
.381	.277		4	2	
4935.056	.048	....	0000	0	
4936.012	.015	Ni	2	1	
4936.546	.512	Cr	1	0	
4937.	.902	Ti	000	.....	bf
4938.471	.467	Ti?	000	1	
4938.708	.....	....	....	0	
4939.243	.416	Fe	2	0	dr
.575				0	
4941.476	.496	Co, Sc	0000	0	
4941.763	.752	Ti	0000	0	
4942.548	.660	Cr	2	0	dr
.793				0	
4943.631	.623	Ce	0000	1	
4944.049	.087	Ce	0000	0	
4944.784	.751	Ce	000	1	
4946.	.568	Fe	3	.....	bf
4947.	.778	....	00	.....	bf
4950.150	.291	Fe	2	0	dr
.412				0	
4953.251	.392	Ni	2	0	dr
.536				0	
4954.878	.986	Cr	2	0	dr
5.116				0	
4955.528	.....	....	....	0	
4957.	.785	Fe	8	.....	bf
4958.302	.431	Ti	00	1	dr
.542				0	
4959.282	.320	Nd	0000	1	
4961.100	.235	....	00	0	dr
.350				0	
4961.583	.564	....	0000	0	
4962.486	.467	Sr?	000	0	
4962.	.751	Fe	2	.....	bf

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
4965.235	.351	Ni	0	0	dr
.474				0	
4968.	.080	Fe	3	.....	bf
4969.966	0.098	Fe	3	0	dr
70.229				0	
4970.564	......	La	....	2	
4971.374	.531	Ni, Ce	1	0	dr
.661				1	
4973.146	.281	Ti-Fe	4	0	dr
.411				0	
4974.638	.642	....	0000	1	w
4975.491	.530	Ti	00	2	
4976.169	.314	Ni	0	0	dr
.633	.508	Ni	1	0	
4978.368	.372	Ti	00	1	
4978.	.785	Fe	3	.....	bf
4979.366	.391	....	000	0	
4980.132	.352	Ni-	4	0	dr
.588				0	
4981.462	.453	....	0000	0	
4981.773	.912	Ti	4	0	dr
2.049				0	
4984.	.297	Ni	2	.....	bf
4985.	.730	Fe	3	.....	bf
4986.290	.403	Fe	1	0	dr
.551				0	
4986.982	......	La	....	1	
4988.291	.313	....	000	1	
4989.010	.130	Fe	2	0	dr
.264	.325	Ti	00	1	
4990.106	.147	Nd	000	1	
4990.544	.625	Fe	0	0	dr
.739				0	
4991.115	.247	Ti	3	1	dr
.348				0	
4991.	.452	Fe, La	2	.....	bf
4993.533	.531	....	0	2	
4994.	.316	Fe	3	.....	bf
4995.220	.208	....	0000Nd?	0	
4997.148	.283	Ti	0	0	dr
.407				0	
4999.554	.689	Ti, La	3	1	dr
.815				0	
5001.166	.165	Ti	0	1	
5001.639	.654	....	000	0	
5002.	.044	Fe	5	.....	bf
5002.491	.510	V	0000	0	
5005.591	.581	....	000	1	
5005.	.896	Fe	4	.....	bf
5006.	.306	Fe	5	.....	bf
5007.285	.398	Ti	3	1	
.646	.461	Fe	2	1	

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5009.633	.829	Ti, Co	00	1	dr
10.001				1	
5011.927	......	Ce	....	1	
5012.108	.252	Fe	4	1	dr
.434	.335	....	1	1	
5012.	.625	Ni	1	.....	bf
5013.890	.871	Ti	0	1	
5013.967	.953	Ce	0000	0	
5014.250	.369	Ti	2	1	dr
.585	.457	Fe	3	0	
5016.216	.340	Ti	2	0	dr
.469				0	
5017.	.762	Ni	3	.....	bf
5018.519	.629	Fe	4	5	dr E
.727				4	
5019.740	......	....	....	0	
5020.050	.208	Ti	2	1	dr
.347				1	
5022.222	.414	Fe	3	0	dr
.574				0	
5023.	.052	Ti	2	.....	bf
5024.242	......	....	....	0	w
5024.900	5.027	Ti	3	0	dr
5.195				0	
5025.725	.749	Ti	1	0	
5025.950	.938	....	000	0	w
5027.	.305	Fe	3	.....	bf
5029.	.805	Fe	1	.....	bf
5030.103	.096	....	0000	1	w
5031.084	.058	Sc	0000	1	
5031.172	.199	....	3	3	
5032.244	.252	C	0000	1	w
5033.700	.714	....	000	1	w
5034.354	.354	C	000	0	
5034.568	.530	....	0000	0	
5034.982	......	....	....	0	
5035.	.542	Ni	5	.....	bf
5036.306	.332	....	0000	0	
5037.968	......	Ce	....	0	
5038.292	.579	Ti	2	1	dr
.890				0	
5039.	.428	Fe	3	.....	bf
5040.020	.138	Ti	3	1	dr
.275				1	
5040.602	.644	C	0000	1	w
5040.926	1.069	Fe	3d?	1	dr
1.380	.255	Fe	4	0	
5041.066	.795	Ca	2	1	dr
2.125	.936	Fe	4	2	
5042.	.367	Ni	1	.....	bf
5043.	.761	Ti	00	.....	bf

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5044.232	.394	Ni, Co-Fe	3	1	dr
.533				0	
5045.451	.454	....	00	0	
5047.951	.....	He?	....	0	
5048.464	.612	Fe	3	0	dr
.770				0	
5050.	.008	Fe	6	.....	bf
5050.905	.919	C	000	0	
5051.558	.683	Ni	1	1	dr
.960	.825	Fe	4	1	
5052.352	.338	....	0N	0	w
5052.795	.803	....	00	0	
5053.038	.056	Ti	0	1	
5053.771	.756	....	00N	0	
5054.253	.261	Ti	000	0	
5056.290	.307	C	000	0	
5057.866	.875	....	0000	0	
5058.509	.674	Fe	00	0	dr
.809				0	
5059.407	.409	....	000	0	
5060.096	.258	Fe	3	1	dr
.413				1	
5061.899	.882	C	00	0	
5062.297	.285	Ti	0	2	
5063.353	.355	C	00	1	
5063.468	.479	C	000	1	
5063.909	.927	....	0000	0	
5064.244	.244	Ti	00	0	
5064.671	.836	Ti	3	0	dr
.974				1	
5065.	.207	Fe	3	.....	bf
	.380	Fe	2	.....	
5066.972	6.908	....	00	1	w
	7.039	....	000		
5068.573	.....	....	....	0	
5068.800	.944	Fe	5	0	dr
9.099				0	
5069.542	.592	Ti	000d	0	
5070.164	.165	....	00	0	
5071.954	.969	....	000N	1	
5072.029	.257	Fe, C	3	1	dr
.551				1	
5072.	.849	Fe	2	.....	bf
5073.238	.....	C	....	0	
5073.630	.637	Ti	00	1	w
5074.714	.932	Fe	5	0	dr
5.096				0	
5075.509	.480	Ce	00	2	
5076.194	.450	Fe, Ce	3	0	dr *
.731				2	
5077.690	.....	Co	....	0	
5078.544	.541	C	000	0	
5078.883	.891	....	0000	1	
5079.003	.158	Fe	3	0	dr
.528	.409	Fe	4	1	
5079.	.921	Fe	4	.....	bf
5080.275	.288	C	0000	2	
5080.599	.714	Ni	4	0	dr
.843				1	
5081.736	.764	Sc	000	2	
5081.943	.942	C	000	0	
5083.180	.205	C	000Nd?	1	
5083.383	.518	Fe	4	0	dr
.635				0	
5083.896	.877	Sc	000	1	
5084.	.279	Ni	3	.....	bf
5084.849	.876	....	000	1	
5085.691	.668	Sc	0	0	
5086.394	.422	....	00	1	
5086.602	.570	C	000	1	
5087.096	.104	Sc	0000	0	
5087.592	.601	Y	1	4	
5088.202	.175	....	000	1	
5089.390	.387	....	000Nd?	1	w
5089.997	0.004	Sc, Nd	0000	0	
5090.810	.954	Fe	5	0	dr
1.100				0	
5092.503	.483	C	00	1	
5092.984	.977	Nd	000	2	
5093.868	.858	C	0000N	0	
5095.332	.348	....	00d?	1	
5096.665	.660	....	0000	0	
5096.930	.908	C, Sc	000	1	
5098.309	.302	C	00N	1	
5098.480	.492	C	000N	0	
5098.	.885	Fe	3	.....	bf
5099.947	.957	....	000	1	
5100.821	.827	....	00	0	
5101.245	.251	C, Sc	000	0	
5101.652	.655	....	000	0	
5102.580	.599	....	000	0	w
5103.319	.297	C	0000	0	
5103.894	.909	C	000	1	
5104.089	.083	C	0000	0	
5105.371	.356	....	0000	0	
5105.571	.718	Fe	4	0	dr
.825				0	
5106.525	.556	C	0000	0	
5106.776	.773	C	000	1	
5107.495	.619	Fe	4	0	dr
.905	.823	Fe	4	0	
5108.066	.056	C	000	1	

* Solar line double.

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5109.277	.291	C	000d?	1	
5109.	.827	Fe	2	.....	bf
5110.182	.188	C	0000	0	
5110.	.574	Fe	5d	.....	bf
5110.921	.938	Cr-C	00	0	
5111.429	.426	....	0000	0	
5111.806	.802	C	000	1	
5112.440	.458	....	000	4	
5113.244	.240	Cr-C	0	0	*
5113.596	.617	Ti	0	0	
5114.402	.431	C	000Nd	1	
5114.732	......	La	....	2	
5115.251 .754	.566	Ni	2	0 0	dr
5116.014	.045	C	0000	0	
5116.837	.849	C, Sc	0000	1	
5117.050	.071	C	000	0	
5117.331	.334	Ce	0000	0	
5118.278	.241	C	0000	1	
5119.296	.292	C, Y	00	1	
5119.541	.555	C	000	0	
5119.815	.820	C	0000	0	
5120.556	.516 .592	C Ti	000 0	 2	
5120.833	.802	C	000	0	
5121.586	.609	....	0000	0	
5122.459	.481	C	0000	0	
5122.596	.613	C	0000	0	
5122.962	.968	Co-C	000	0	
5123.163	.178	La	000	2	
5123.364	.390	Y	0	2	
5123.751 4.002	.899	Fe	3	0 0	dr
5124.209	.219	C	000	0	
5124.901	.939	C	0000	0	
5125.876	......	Co	....	0	
5126.212 .520	.371	Fe-Co	2	0 0	dr
5127.382 .698	.533	Fe, Ti	3	0 0	dr
5129.165 .701	.336 .546	Ti? Ni	3 2	0 1	dr E
5130.763	.757	C, Nd	000	5	
5131.779	.771	C	0000	2	
5132.512	.523	C, Nd	000	1	
5132.857	.843	C	00	2	
5133.655 4.008	.870	Fe	4	1 1	dr
5134.506	.505	C	0000	0	
5134.862	.849	C	0000	0	
5135.347	.355	Y	0000	0	
5135.835	.752 .880	C,– C,–	000 000	1	w
5136.411	.443	....	000	0	
5136.614	.625	C	0000	1	
5136.851	.835	C	0000	0	
5136.985	.969	....	000	1	
5137.	.250	Ni, Cr	3	.....	bf E
5137.756	.753	C,–	000	1	
5138.260	.279	C	0000	0	
5138.496	.518	V	0000	0	
5138.645	.690	C	0000	0	
5139.	.427	Fe	4	.....	bf
5139.539 .775	.644	Fe	4	0 1	dr
5140.092	.094	C	0000	0	
5140.566	.553	Ce	0000	0	
5141.389	.386	C,–	000	2	
5141.775 2.052	.918	Fe	3	1 1	dr
5142.288	.279	....	0000	0	
5142.	.693	Fe	4d?	.....	bf
5142.966	.958	Ni	2	1	
5143.	.111	Fe	3	.....	bf
5143.499	.511	C	000	0	
5143.748	.764	C	000	0	
5144.214	.203	....	0000	0	
5144.742	.758	C,–	000	0	
5144.852	.847	Cr, C	00	0	
5145.094	.098	C	0000	1	
5145.386	.403	C	0000	0	
5145.652	.636	Ti-C	0	0	
5146.304	.291	C,–	00	4	
5146.656	.659	Ni–	3	0	
5146.941	.945	Co-C	000d?	1	
5147.841	.871	C,–	000	1	
5147.983	.992	C,–	000	1	
5148.	.222 .410	Fe Fe	2 3	....	bf
5149.209	......	C-Co	....	1	
5150.340	.363	....	00	0	
5150.844	.842	C	0000	2	w
5151.	.020	Fe	4	.....	bf
5151.657	.628	C	0000N	0	
5151.953 2.229	2.087	Fe	3	0 0	dr
5153.335	.337	C	0000	1	
5153.442	.414	Fe-C	1	0	
5154.171 .346	.244	Ti-Co	2	0 0	dr E
5154.552	.579	C	000	2	w
5155.050	.028	C	0000	0	

* Blend.

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5155.701	.694	C,–	000	1	
5155.945	.935	Ni	2	0	
5156.518	.530	Co	000	0	
5156.728	.728	C	0000	1	
5156.927	......	La	....	1	
5157.779	.783	C	000	1	
5157.944	.915	C	000	1	
5158.	.152	Ni	00	.....	bf
5158.702	.701	C	000	2	
5159.072	.026	Co-C	0000N	1	
5159.627	.634	C	000	1	
5159.937	.946	....	0000	1	
5160.730	.419	C,–	00N	1	
5160.569	.554	C	0000	0	
5161.199	.194	C	000	1	
5161.362	.353	C	000	1	
5161.907	.910	C	000	1	
5162.161	.153	C?	0000	0	
5162.	.449	Fe, C	5	.....	bf
5162.716	.690	C	0000	1	
5163.064	.074	Ti, C	000	0	
5163.573	.585	C,–	000	0	
5163.769	.756	C, La	000	0	
5164.004	.007	C	0000	0	
5164.163	.172	C	0000	0	
5164.395	.404	C,–	000	1	
5164.564	.562	....	0000	0	
5164.942	.950	C	0000	0	
5165.201	.209	C	0000	2	
5165.290	.297	C	0000	1	
5165.436	.416	C	0000	0	
5166.320	.454	Cr-Fe	3	0	dr
.578				0	
5167.364	.497	Mg	15	2	dr
.780	.678	Fe	5	1	
5169.	.069	Fe	3	.....	bf
5169.149	.220	Fe	4	5	dr E
.328				8	
5170.970	.937	Fe	0	0	
5171.659	.778	Fe	6	0	dr
.925				0	
5172.706	.856	Mg	20	5	dr
3.004				4	
5173.782	.917	Ti	2	0	dr
4.056				2	
5175.528	.575	....	000	0	dr
.659				0	
5176.330	.305	Co	000	0	
5176.475	.735	Ni	1	0	dr
.939				0	
5178.421	......	....	....	0	
5178.682	.644	V	000	0	
5179.948	.958	Nd	000	2	
5180.066	.233	Fe	1	0	dr
.388				0	
5180.746	.747	....	000	0	
5181.351	.334	....	000	0	
5182.754	.761	....	0000	0	
5183.604	.791	Mg	30	6	dr
.935				5	
5184.356	.445	Fe	2	0	dr
.718	.738	Fe, Ni	1	1	
5185.962	6.073	Ti	2	0	dr E
6.218				0	
5187.624	.620	Ce	000	2	
5188.753	.863	Ti	2	2	dr E
.903				1	
5189.726	.744	....	000	0	
5191.537	.629	Fe, Ce	4	1	dr
.761				2	
5192.160	.155	Cr	00	1	
5192.784	.785	Nd	000	2	
5193.025	.139	Ti	2	0	dr
.255				0	
5193.657	.669	Cr	000	0	
5194.018	.027	....	0000	0	
5196.120	.227	Fe	1	1	dr
.340				0	
5196.630	.613	Cr	0	0	
5197.735	.743	....	2	9	
5198.769	.888	Fe	3	0	dr
9.002				0	
5200.320	.355	Cr	00	0	
5200.577	.590	V, Y	0	3	
5201.259	.260	Ti	000	1	
5202.314	.439	Fe?	2	1	dr
.626	.516	Fe	4	1	
5203.126	.118	....	0000	0	
5204.564	.680	Cr	5	1	dr
.875	.768	Fe	3	1	
5205.887	.897	Y	0	5	bf
5206.	.215	Cr-Ti	5	0	
5206.739	.712	V	000	0	
5207.650	.791	....	000N	0	dr
.985				0	
5208.028	.111	Ti	00	1	dr
.218				0	
5208.483	.596	Cr	5	1	dr
.933	.776	Fe	2	0	
5210.196	.204	Co	0000	1	
5210.433	.555	Ti	3	0	dr
.687				0	
5211.006	.015	....	000	0	
5211.699	.700	Fe	00	0	

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5212.497	.503	Ti, Nd	0000	2	
5212.854	.859	Co	000Nd?	2	
5213.156	.155	....	0000	0	
5214.292	.286	Cr	00	1	
5215.	.353	Fe	3	.....	bf
5216.	.437	Fe	3	.....	bf
5217.	.552	Fe	3	.....	bf
5218.328	.369	Fe	1	0	
5219.201	.186	....	0000	1	
5220.289	.250 .358	.... Ni	000 0	2	
5221.058	.078	....	000	0	
5221.	.928	Cr	0	.....	bf
5222.	.556	Cr	00	.....	bf
5222.846	.849	Ti, Cr	00	1	
5223.789	.791	Ti	000	1	
5224.246	.239	Cr	000N	0	
5224.693	.712	Ti, Cr	00	1	
5225.154	.101 .198	Cr Cr, Ti,	0 00	1	
5225.546 .833	.695	Fe	2	0 0	dr
5226.610 .785	.707	Ti	2	4 3	dr E
5227.	.362	Fe	5d?	.....	bf
5228.258	.268	Cr	000	0	
5228.405 .702	.546	....	1	0 0	dr
5230.	.030	Fe	4	.....	bf
5230.195 .554	.382	Co, Cr	00	0 0	dr
5231.144	.151	....	0000	0	
5232.676	.681	....	000	0	
5233.	.122	Fe	7	.....	bf
5234.216	.255	....	0000	0	
5234.374	.380	V, Nd	000	1	
5234.788	.791	....	2	8	dr?
5235.459 .838	.557 .672	Fe Ni	1 00	0 0	dr
5237.240	.254	Ce	0000	1	
5237.488	.493	Cr	1	2	E
5238.644 .892	.742	Ti	000N	0 0	dr
5239.975	.992	Sc	1	3	
5240.637	.639	....	000	0	
5241.028	.040	V	000	1	
5241.944	.....	Ce	....	0	
5242.517 .804	.658	Fe	2	0 0	dr
5243.514	.526	Cr	00	0	
5243.	.946	Fe	1	.....	bf
5245.095	.118	....	0000	0	
5246.320	.310	....	0000	0	
5246.972	.946	....	000	1	
5247.461	.466	Ti	000	1	
5247.	.737	Cr	2	.....	bf
5249.747	.751	Nd	0000	4	
5250.178	.193	Co	0000	1	
5250.241 .508	.385	Fe	2	0 0	dr
5250.667 .968	.817	Fe	3	0 1	dr
5252.832	.....	Ce	....	0	
5253.	.633	Fe	2	.....	bf
5254.822	.830	Co	0000	1	
5255.028 .280	.121 .295	Fe Cr	3 0	0 1	dr
5255.674	.687	Nd	0000	4	
5255.996	.973	Ti	0000	0	
5257.104	.100	Sr	00	2	
5257.760	.814	Co	0	1	
5259.900	.912	Ce	0000	2	
5260.113	.142	Ti	000	0	
5260.438 .673	.561	Ca	0	0 0	dr
5261.750 .979	.876	Ca-Cr	3	0 0	dr
5262.293	.321	Ti	1	1	
5262.	.419	Ca	3	.....	bf
5263.	.486	Fe	4	.....	bf
5264.055	.038	Fe	0	0	
5264.195 .527	.329 .415	Cr Ca	4 3	0 0	dr
5264.974	.976	....	0	4	
5265.321	.321	Cr	00	0	
5265.570 6.011	.729 .893	Ca Ni-Cr	3 2	0 0	dr
5266.459	.482	Co	000	1	
5266.622 .844	.738	Fe	6	0 0	dr
5267.284 .568	.447	....	00	0 0	dr
5268.515	.515	Ni	0	0	
5268.665	.670	....	000	0	
5268.713 .834	.784	Co	00	1 1	dr
5269.115	.125	....	000	0	
5269.602 .838	.723	Fe	8d?	2 1	dr
5270.293 .664	.438 .558	Ca Fe	3 4	0 0	dr
5271.206	.228	....	00	0	
5272.198	.171	Cr	00	0	

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5273.200	.339	Fe	3	0	dr
.638	.558	Fe-Cr	2	1	
5274.407	.408	Ce	00	3	
5275.141	.148	....	0	0	
5275.340	.340	Cr	00	1	
5275.	.454	....	1	.....	bf
5276.149	.169	Fe?	3	10	
5276.384	.344	Co	000	0	
5277.040	.047	Nd	000	1	
5280.054	.048	....	0	0	
5280.256	.239	....	00	0	
5280.803	.799	Co	00	2	
5281.647	.681	....	000N	0	
5281.858	.971	Fe	5	0	dr
2.121				0	
5283.649	.802	Fe	6	0	dr
.929				0	
5284.281	.281	....	1	6	
5287.349	.351	Cr	000	0	
5287.713	.741	Co	0000N	0	
5287.958	.958	Co	000	0	
5288.554	.705	Fe	2	0	dr
.805				0	
5289.976	.988	Y	000	0	
5291.006	0.984	La	000	0	
5292.365	.388	....	000N	0	
5292.803	.762	Fe	0	0	
5293.071	.044	....	000	0	
5293.334	.341	Nd	00	3	
5293.550	.543	....	000	0	
5296.	.872	Cr	3	.....	bf
5297.399	.407	Cr, Ti	000	0	
5298.334	.455	Cr	4	0	dr
.574				0	
5300.150	.152	Ti	00	0	
5300.784	.929	Cr	2	0	dr
1.062				1	
5302.145	.....	Sc, La	....	2	w
5302.	.480	Fe	5	.....	bf
5302.818	.829	....	000	0	
5303.364	.401	Ce	0	0	
5303.718	.738	La	000	2	
5306.035	.040	....	0	1	
5306.640	.665	....	000	1	
5307.405	.541	Fe	3	0	dr
.648				0	
5308.594	.599	Ce	0	1	
5310.392	.417	Co	000	0	
5310.882	.866	....	0	0	
5311.634	.650	Nd	000	1	
5311.953	.962	....	000	0	
5312.838	.835	Co	00	1	
5313.042	.031	Cr	0	0	
5313.768	.758	....	1	1	
5316.735	.790	Fe	4	8	dr E
.842				8	
5316.965	.958	Co–	2	6	
5318.537	.534	Sc	00N	1	
5318.975	.955	Cr, Fe	0	0	
5319.276	.392	....	000	0	dr
.660	.502	....	000	0	
5320.005	9.999	Nd	00	3	
5320.	.220	Fe	0	.....	bf
5321.	.293	Fe	2	.....	bf
5322.964	.994	....	000	2	
5325.468	.460	Co	00	1	
5325.745	.738	....	2	3	
5326.144	.139	Co	000N	0	
5328.123	.236	Fe	8d?	1	dr
.367				1	
5328.	.722	Fe	4	.....	bf
5330.744	.748	Ce	000	2	
5332.727	.849	Co, Fe	1	0	dr
3.222	.089	Fe	4	0	
5333.849	.832	Co	000	1	
5334.391	.403	Sc	000	0	
5335.033	.050	Co	1	1	
5336.361	.356	Co	000	0	
5336.698	.660	Nd	0000	0	
5336.922	.974	Ti,–	4	3	w E
5337.517	.....	Co	....	0	
5337.897	.910	Ce	0	2	
5339.708	.719	Co	000	0	
5340.	.121	Fe	6	.....	bf
5340.651	.639	Cr	0	0	
5341.	.213	Fe	7	.....	bf
5341.490	.514	Co	00	1	
5341.	.670	Ti	000	.....	bf
5342.892	.890	Co	1	3	
5343.552	.570	Co	0	1	
5343.	.622	Fe	2.	.....	bf
5344.770	.767	Co	000N	0	
5345.	.991	Cr	5	.....	bf
5347.687	.712	Co	00	0	
5348.	.511	Cr	4	.....	bf
5349.286	.283	Co	000	0	
5349.506	.653	Ca	4	0	dr
.792				0	
5350.052	.059	Mn	00	0	
5350.283	.281	....	00	1	
5350.537	.547	....	00	2	
5351.253	.261	Ti	00	0	
5352.237	.234	Co	1	2	
5352.625	.591	....	000	0	

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5353.703	.702	Co	0	6	
5356.291	.270	Sc	000	0	
5357.160	.178	Nd	000	1	
5358.167	.306	....	00	0	dr
.460				0	
5359.098	.127	Co	000N	0	
5359.386	.389	Co	00	1	
5359.695	.714	....	000	0	
5361.666	.697	Nd	000	4	
5363.052	.058	Co–	3	8	
5366.947	.950	Co	000	0	
5368.729	.741	....	000	0	
5369.100	.125	Co	0000	0	
5370.540	.522	Cr	00N	0	
5371.534	.656	Cr?	4	2	dr
.794	.734	Fe	3	1	
5372.120	.121	Nd	000	3	
5373.800	.905	Fe, Cr	2	0	dr
4.033				0	
5375.558	.516	Sc	000	0	
5377.	.028	Fe	0	.....	bf
5377.798	.800	Mn	2N	1	E
5379.652	.775	Fe	3	0	dr
.883				0	
5380.	.516	....	0N	.....	bf
5381.152	.221	Ti, La	2	2	E
5381.468	.514	Co	0000	1	
5381.955	.980	Co	000	1	
5383.201	.209	....	000	0	
5386.092	.089	Nd	000	1	
5386.977	.989	Ce	0000	1	
5387.778	.769	Cr	00	0	
5390.194	.203	Ti	000	0	
5390.600	.573	Cr	000	0	w
5391.535	.660	Fe	2	1	dr
.921	.820	Fe	1	1	
5393.573	.584	Ce	000	3	
5394.	.876	Mn	2	.....	bf
5395.317	.422	....	0	0	dr
.555				0	
5396.453	.448	....	00	0	
5397.229	.344	Fe	7d?	1	dr
.459				1	
5399.694	.675	Mn	1Nd?	0	
5400.802	.831	Cr	0N	0	
5402.158	.151	V	0000	1	
5402.686	.....	....	....	0	
5402.989	.982	Y	0	2	
5405.190	.192	Cr	00	0	
5405.	.554	....	1	.....	bf
5405.874	.989	Fe	6	0	dr
6.102				0	

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5406.391	.388	....	0000N	0	
5407.413	.587	Mn	0	1	dr
.824	.688		0	1	
5409.253	.339	Fe, Ce	2	0	dr?
.444				2	
5409.833	.823	Ti	000	1	
5410.	.000	Cr	4	.....	bf
5411.448	.428	Ni	1	1	w
5411.774	.764	....	0000	0	
5412.868	.997	Mn	00	0	dr
3.152				0	
5413.889	.889	Mn	00N	0	w
5414.295	.279	Ce	00	3	
5415.	.416	Fe-V	5	.....	bf
5416.618	.587	Nd	0000	1	
5417.135	.247	Fe	0	0	dr
.362				0	
5418.211	.....	....	....	0	
5418.972	.979	Ti	1	2	w E
5420.369	.510	Mn	0N	1	dr
.756	.613		0N	1	
5421.176	.134	....	00	1	
5421.780	.783	Nd	0000N	1	w
5424.764	.860	Ni	1	0	dr
.982				0	
5425.473	.464	....	1	4	
5428.704	.....	....	....	0	
5429.362	.349	Ti	00	2	
5429.	.717	....	1	.....	bf
5429.802	.911	Fe	6d?	1	dr
30.012				1	
5430.	.062	....	0	.....	bf
5431.720	.747	Nd	000	1	w
5432.608	.753	Mn	1Nd?	1	dr
.924				1	
5433.195	.160	Fe	2	1	
5434.637	.740	Fe	5	0	dr
.855				0	
5444.796	.796	Co	00	3	
5446.425	.436	Sc	0000	0	
5446.643	.797	Ti	2	0	dr
.996				1	
7.245	7.130	Fe	6d?	0	
5447.726	.737	....	000	0	
5448.411	.582	....	00	0	dr
.609				0	
5449.427	.....	Ce, Nd	....	0	
5451.317	.330	Ce, Nd	000	1	
5452.	.309	....	00	.....	bf
5454.313	.326	....	000	0	
5454.776	.783	Co	00	2	
5455.	.834	Fe	4	.....	bf

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5457.	.670	Mn	00	.....	bf
5460.558	.721	Ti	00	0	dr
.897				0	
5462.	.705	Ni	1	.....	bf
5464.390	.490	Fe	0	0	dr
.602				0	
5466.472	.609	Fe	3	0	dr
.779				0	
5468.578	.601	Ce	000Nd?	2	
5470.634	.802	Mn	0	1	dr
1.018	.883		0	1	
5472.499	.503	Ce	000	2	
5473.581	.594	Ce	000	1	
5473.955	4.113	Fe	3	0	dr
4.278				0	
5474.278	.436	Ti?	00	0	dr
.628				0	
5476.981	7.123	Ni	5	0	dr
7.248				0	
5477.929	.901	Ti	00	0	
5478.558	.578	....	00	0	
5480.916	1.071	Fe	1	0	dr
1.235				0	
5481.	.652	Fe, Ti	1	.....	bf
5481.925	2.078	Ti, Sc	00	0	dr
2.186				0	
5483.	.307	Fe	1	.....	bf
5484.826	.846	Sc	000	0	
5485.229	.266	Nd	0000	0	
5485.901	.915	Nd	0000	2	
5487.	.354	Fe	1	.....	bf
5487.799	.959	Fe	3	0	dr
8.107				1	
5488.396	.374	V-Ti	00Nd?	0	
5489.879	.893	Co	000	2	w
5490.	.367	Ti	0	.....	bf
5490.892	.905	....	0	2	
5491.890	.897	....	0000	0	w
5493.092	.095	....	00	1	
5493.584	.709	Fe	1	0	dr
.814				0	
5494.223	.193	Nd	0000	0	
5497.607	.735	Fe	5	1	dr
.842				0	
5498.107	.105	....	000	0	
5498.931	.955	....	0000	0	
5501.546	.683	Fe	5	0	dr
.807				0	
5503.136	.286	Fe	1	0	dr
.433				1	
5504.111	.117	Ti, La	0	2	
5505.950	6.095	Mn	1	0	dr
6.221				0	
5506.697	.719	....	000	0	
5507.	.000	Fe	5	.....	bf
5507.974	.985	V	000	0	
5508.852	.840	....	0	0	
5510.096	.120	Y	0	3	
5510.832	.829	....	00	0	w
5510.946	.942	....	00	0	
5511.653	.644	....	000	0	
5512.280	.266	Ce	00	3	
5513.005	.198	Ca	4	0	dr
.360				0	
5513.780	.769	....	0000	0	
5514.427	.563	Ti	2	0	dr
.890	.753	Ti	2	0	
5516.803	.950	Mn	0	0	dr
7.137	.034	Mn	0	0	
5519.605	.633	....	000	0	
5520.712	.727	Sc	00N	0	
5521.770	.799	Y	00	1	
5522.483	.665	Fe	2	0	dr
.828				0	
5523.810	.783	....	000N	0	
5524.686	.684	....	000	0	
5525.332	.347	Co	00	1	
5525.	.765	Fe	2	.....	bf
5526.427	.405	....	000N	0	
5526.976	7.033	Sc	3	2	dr
7.108				2	
5527.776	.796	Y	000d	0	
5528.092	.084	....	0000N	0	
5528.	.641	Mg	8	.....	bf
5530.892	.997	Ti	00N	0	dr
1.109				0	
5532.336	.353	....	000	0	
5532.794	.968	....	1	0	dr
3.239	.092	....	0	0	
5534.061	.011	Nd	000d	0	
5534.527	.504	....	000	0	
5535.058	.061	....	2	7	
5535.424	.644	Fe	2	0	dr
.830				0	
5536.304	.300	....	000	0	
5536.518	.492	....	000	0	
5537.824	.928	Mn	00	0	dr
8.098	.025	Mn	00	0	
5540.210	.192	....	0000	0	
5543.980	4.157	Fe	2	0	dr
4.324				0	
5544.834	.831	Y	000	2	

TABLE I—*Continued*

Observed λ	Rowland			Chr. Int.	Remarks
	λ	Element	Intensity		
5546.164	.147	....	000	1	w
5546.	.732	Fe	2	.....	bf
5547.108	.215	Fe, V	1	0	dr
.323				0	
5549.990	......	....	....	0	
5553.308	.346	....	000N	0	
5557.137	.196	Ce	000	0	dr
.407	.287		000	0	
5558.137	.136	....	0	0	
5559.080	.068	V	000Nd?	0	
5560.278	.434	Fe	2	0	dr
.563				0	
5560.896	.911	....	0000	0	
5562.773	.933	Fe	2	0	dr
3.094				0	
5563.674	.824	Fe	3	0	dr
.984				0	
5565.709	.700	Ti	00	1	
5565.	.931	Fe	3	.....	bf
5567.337	.367	....	0000N	0	
5567.488	.621	Fe	2	0	dr
.732				0	
5569.249	.249	....	0000	0	
5569.662	.848	Fe	6	0	dr
.968				0	
5576.	.320	Fe	4	.....	bf
5578.746	.946	Ni	1	0	dr
9.106				0	
5580.663	.672	....	000	0	
5882.063	.198	Ca	4	1	dr
.324				1	
5583.174	.186	....	000	0	
5584.700	.729	V	000	0	
5584.	.988	Fe	0	.....	bf
5585.396	.397	....	000	0	
5586.886	.991	Fe	7	1	dr
7.094				0	
5587.727	.800	Fe	0	0	dr
889				0	
5588.836	.985	Ca	6	1	dr
9.122				1	
5589.431	.582	Ni	0	0	dr
.768				0	
5590.222	.343	Ca	3	1	dr
.465				1	
5591.024	.039	Ti	000	0	
5591.574	.586	Sc	000	0	
5592.378	.375	Ni	0	1	
5592.	.487	Fe, Ni	1	.....	bf
5593.858	.961	Ni	0	0	dr
4.078				0	
5594.	.691	Ca	4	.....	bf

Observed λ	Rowland			Chr. Int.	Remarks
	λ	Element	Intensity		
5595.914	.906	....	0000	0	
5598.358	.524	Fe	1	0	dr
.845	.711	Ca	4	1	
5599.533	......	....	....	0	
5601.348	.505	Ca	3	0	dr
.628				0	
5602.923	.995	Fe	1	1	dr
	3.083	Ca	3		
3.305	.186	Fe	4	1	
5603.867	.993	....	00	0	dr
4.131				0	
5606.108	.122	....	000	0	
5607.	.887	....	00	.....	bf
5608.386	.393	....	000	0	
5610.461	.467	Ce	000	1	
5612.556	.573	....	000	0	
5613.904	.929	Ce	000N	0	
5614.992	.997	Ni, Ce	0	0	
5618.144	.130	....	000	0	
5618.712	.858	Fe	1	0	dr
9.016				0	
5619.669	.824	....	0	0	dr
.931				0	
5620.506	.715	Fe	0	0	dr
.850				0	
5621.422	.438	....	000N	0	
5622.970	.996	....	000	0	
5624.116	.245	Fe	1	0	dr
.373				0	
5625.102	.096	V	000	0	
5625.745	.755	....	000	0	
5627.006	.034	....	000	0	
5627.718	.723	....	000	1	
5628.190	.239	....	000N	0	
5633.351	......	Ce	....	0	
5633.994	4.171	Fe	3	0	dr
4.330				0	
5636.	.045	Fe	1	.....	bf
5638.365	.488	Fe	3	0	dr
.646				0	
5641.	.206	....	1	.....	bf
5641.551	.667	Fe	2	0	dr
.791				0	
5642.	.112	Ni	0	.....	bf
5644.348	.365	Ti	0	2	
5645.	.830	Si	1	.....	bf
5646.810	.904	....	00	0	dr
.990				0	
5648.792	.796	Ti	00	1	
5649.652	.611	Cr	00N	0	w
5649.	.898	Fe-Ni	od	.....	bf

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5651.532	.691	Fe	0	0	dr
.817				0	
5652.440	.542	Fe	1	0	dr
.640				0	
5653.934	4.091	Fe	1	0	dr
4.268				0	
5655.562	.715	Fe	2	0	dr
.884				0	
5658.106	.097	Y, Sc	2	1	w
5658.578	.561	Sc	0	3	
5658.643	.753	Fe	1	0	dr
	.884	Cr	0		
9.170	.052	Fe	4	0	
5661.402	.418	....	0000	0	
5662.344	.374	Ti	0	1	
5663.134	.155	Ti, Fe, Y	1	3	
5664.	.218	Ni-Cr	1N	.....	bf
5664.770	.797	....	000	0	
5665.632	.775	Si	1N	1	dr
.884				0	
5667.364	.368	Sc	0	2	
5667.634	.739	Fe	2	0	dr
.855				0	
5668.586	.593	V	000	0	
5669.136	.130	Ce, Nd	0000	1	
5670.154	.163	Ni, Ce	0	0	
5671.066	.071	V	0	1	
5671.715	.712	....	00N	0	
5672.039	.047	Sc	0	1	
5677.732	.919	Ce	00	0	dr
8.095				0	
5679.	.249	Fe	3	.....	bf
5682.695	.869	Na	5	1	dr
3.026				1	
5684.415	.415	Sc	1	2	
5687.056	.063	Sc	000	1	
5687.	.697	....	0	.....	bf
5688.267	.436	Na	6	1	dr
.619				1	
5688.736	.759	Nd	0000	3	
5689.694	.694	Ti	0	1	
5690.251	.286	....	0000	0	
5690.484	.646	Si	3	0	dr
.770				0	
5693.669	.865	Fe	3	0	dr
4.056				0	
5694.959	.962	Cr	0	1	
5695.180	.207	Ni	2	0	
5696.905	.869	....	0000N	0	
5698.051	.047	....	0000Nd?	0	
5698.	.242	Fe	0	.....	bf
5698.	.555	Fe, Cr	1	.....	bf
5698.754	.746	V	1	2	
5700.356	.402	Sc	00	0	
5701.	.323	Si	1N	.....	bf
5702.455	.543	Cr	0	0	dr
.676				0	
5702.857	.876	Ti	000	1	
5703.580	.591	....	0000	0	
5703.785	.797	V	1	1	
5705.969	6.215	Fe, Nd	3	0	dr
6.424				1	
5707.202	.204	V	0	0	
5708.470	.622	Si, Nd	3N	1	dr
.769				0	
5709.472	.601	Fe	5	0	dr
.947	.775	Ni	5	0	
5711.123	.313	Mg	6	0	dr
.462				0	
5712.	.098	Fe	3	.....	bf
5712.	.357	Fe	2	.....	bf
5714.102	.120	Ti	000	1	
5714.	.380	Fe	0	.....	bf
5715.473	......	Ce	....	1	
5716.653	.671	Ti	00	0	
5718.	.055	Fe	4	.....	bf
5723.986	4.107	....	0	0	dr
4.224				0	
5727.242	.271	Ti-V	2N	2	
5729.122	.096	Y	00d?	0	
5730.114	.116	....	0000	0	
5731.399	.437	V	00	1	w
5731.845	.984	Fe	4	0	dr
2.146				0	
5732.941	.948	....	000	0	
5737.300	.288	V	0	0	
5740.182	.195	Ti	0	0	
5748.018	.176	Fe	2	0	dr
.374				0	
5750.757	.723	....	000	0	w
5753.701	.860	-Cr	1N	0	dr
.997				0	
5754.750	.881	Ni	5	0	dr
5.024				0	
5756.390	.410	....	0000	0	
5758.738	......	....	....	0	
5758.967	.978	....	000	0	
5760.908	1.052	Ni	2	0	dr
1.194				0	
5761.678	.800	....	⊙	0	dr
.906				0	
5762.474	.479	Ti	000Nd?	3	
5763.084	.218	Fe	6	0	dr
.359				1	

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5766.547	.550	Ti	0	2	
5769.094	.120	Ce	000N	1	
5769.285	.295	La	000	2	w
5770.741	.714	Ce	000Nd?	1	w
5772.628	.630	V	000	0	
5774.243	.250	Ti	0	2	
5775.160	.304	Fe	4	0	dr
.422				0	
5775.970	.969	....	0000	0	w
5780.922	1.024	Fe	0	0	dr
1.202	.130	Cr, Ti	00	0	
5782.198	.313	....	3	0	dr
.507	.390	Cu?	3	0	
5784.760	.879	Fe	1	0	dr
.992				0	
5785.372	.498	Fe	3	0	dr
.625				1	
5786.209	.193	Ti, Cr	0N	3	
5786.416	.373	....	000	1	
5788.	.141	Cr	4	.....	bf
5788.572	.504	....	000	0	w
	.611	Cr	00		
5789.551	.565	....	0000	0	
5791.064	.174	Cr	4	0	dr
.366	.243	Fe	3	1	
5793.127	.292	....	3	0	dr
.421				0	
5794.020	.137	Fe	2	0	dr
.243				1	
5797.816	.815	Ti, La	000	2	
5798.	.077	....	3	.....	bf
5804.473	.479	Ti	0	2	
5804.990	.996	....	0000	1	w
5805.992	.986	La	0	0	
5809.	.439	Fe	4	.....	bf
5811.825	.823	Nd	000Nd?	1	w
5812.	.139	Fe	0	.....	bf
5815.	.441	Fe	0	.....	bf
5817.159	.299	V	0	0	dr
.456				0	
5817.726	.708	....	000	0	
5827.968	8.097	....	0	0	dr
8.253				0	
5830.891	.895	V	000	0	
5835.482	.475	....	000	0	
5842.619	.600	Nd	000	1	
5845.346	.509	....	0	0	dr
.612				0	
5846.494	.487	V	00	1	
5853.796	.902	Ba	5	1	dr
4.012				1	
5855.	.300	Fe	1	.....	bf

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
5857.518	.674	Ca	8	0	dr
.820				0	
5862.	.582	Fe	6	.....	bf
5863.906	.933	La	0000	1	
5866.548	.675	Ti	3	1	dr
.800				0	
5867.	.785	Ca	2	.....	bf
5875.838	......	He	....	50	
5876.174	......	He	....	5	
5879.514	.506	....	0000	0	
5884.	.028	Fe	4	.....	bf
5889.979	0.186	Na	30	3	dr
90.376				3	
5895.984	6.155	Na	20	3	dr
6.347				3	
5905.725	.895	Fe	4	0	dr
6.073				0	
5916.340	.475	Fe	3	1	dr
.623				0	
5930.	.406	Fe	6	.....	bf
5937.828	8.035	Ti	000	0	dr
8.222				0	
5949.	.566	Fe	1	.....	bf
5952.	.943	Fe	4	.....	bf
5956.770	.923	Fe	4	0	dr
7.084				0	
5965.894	6.055	Ti	2	0	dr
6.231				1	
5967.684	.720	....	0000	1	w
5978.696	.768	Ti	1	0	dr
.858				0	
5983.760	.908	Fe	5	0	dr
4.040				0	
5985.	.040	Fe	6	.....	bf
5987.140	.290	Fe	5	0	dr
.451				0	
5991.605	.600	....	2	3	
6003.079	.239	Fe	6	0	dr
.416				0	
6006.587	.605	....	00	0	
6008.632	.785	Fe	6	0	dr
.941				0	
6013.556	.715	Mn	6	1	dr
.878				1	
6016.700	.861	Mn	6	1	dr
7.015				1	
6018.009	......	....	....	0	
6021.853	2.016	Mn	6	1	dr
2.171				1	
6024.	.281	Fe	7	.....	bf
6027.133	.274	Fe	4	1	dr
.421				0	

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
6034.416	.440	Nd	0000	0	
6042.155	.315	Fe	3	0	dr E
.447				0	
6043.580	......	Ce	....	1	
6049.327	.337	Co	000N	1	w
6056.178	.227	Fe	5	0	dr
.364				0	
6060.860	.853	....	0000	0	
6065.557	.709	Fe	7	1	dr
.852				1	
6078.420	.410	....	0000N	0	
6081.655	.665	V	0	0	
6082.628	.640	Co	000Nd?	0	
6082.	.930	Fe	1	.....	bf
6084.320	.325	....	0	2	
6085.	.470	Ti, Fe	2	.....	bf
6086.874	.885	Co	0000N	1	w
6090.406	.429	Ti, V	2	0	
6091.231	.395	Ti	0	0	dr
.577				0	
6092.114	.133	....	1	0	
6098.864	.870	....	00	1	
6102.780	.937	Ca	9	1	dr
3.105				1	
6103.	.400	Fe	4	.....	bf
	.514	Fe	1	.....	bf E
6108.164	.334	Ni	6	1	dr
.500				0	
6111.	.290	Ni	2	.....	bf
6111.864	.872	V	0d?	1	
6113.551	.538	....	0	1	
6119.736	.740	V	1	0	
6119.956	.970	Ni	0	1	E
6122.	.434	Ca	10	.....	bf
6125.054	.236	Ni	1	0	dr E
.403				0	
6135.562	.580	V	00N	1	
6136.665	.829	Fe	8	1	dr
.982				1	
6137.	.915	Fe	7	.....	bf
6141.816	.938	Fe, Ba	7	2	dr
2.065				2	
6146.422	.445	Ti	000	0	
6147.932	.950	Fe	2	2	E
6149.457	.458	Fe, Nd	2	2	w E
6150.338	.360	V	0Nd?	0	
6151.037	.052	Y	0000	1	
6151.	.834	Fe	4	.....	bf
6154.315	.438	Na	2	0	dr
.540				0	
6157.	.945	Fe	5	.....	bf
6160.	.956	Na	3	.....	bf
6162.	.390	Ca	15	.....	bf
6165.	.577	Fe	3	.....	bf
6166.521	.651	Ca	5	0	dr
.790				0	
6169.	.249	Ca	6	.....	bf
6169.	.778	Ca	7	.....	bf
6173.426	.553	Fe	5	0	dr
.687				0	
6180.	.420	Fe	5	.....	bf
6188.080	.210	Fe	4	0	dr
.331				1	
6191.	.393	Ni	6	.....	bf
6191.612	.779	Fe	9	0	dr
.930				0	
6199.392	.398	V	0	1	
6200.370	.527	Fe	6	1	dr
.680				1	
6204.	.825	Ni	1	.....	bf
6210.869	.895	Sc	00N	0	
6213.497	.644	Fe	6	1	dr
.811				1	
6215.241	.360	Fe	5	0	dr
.489				0	
6219.378	.494	Fe	6	1	dr
.660				1	
6229.340	.437	Fe	1	0	dr
.539				0	
6230.	.943	V-Fe	8	.....	bf
6232.639	.856	Fe	3	1	dr
3.040				1	
6237.	.534	....	3	.....	bf
6238.592	.598	Fe	2	3	E
6239.611	.585	Sc	00	0	
6240.737	.863	Fe	3	1	dr
.988				1	
6243.300	.320	....	1	0	
6245.802	.832	Sc–	1	0	
6246.398	.535	Fe	8	1	dr
.666				1	
6247.777	.774	Fe	2	2	E
6252.658	.773	Fe	7	1	dr
.901				0	
6256.	.572	Ni-Fe	6	.....	bf
6265.198	.348	Fe	5	0	dr
.494				0	
6270.259	.442	Fe	3	0	dr
.608				0	
6272.239	.....	Ce	....	1	
6274.049	.....	....	....	0	
6280.679	.833	Fe	3d	0	dr
.977				1	
6287.023	.009	V	0000N	0	

TABLE I—*Continued*

Observed λ	Rowland λ	Rowland Element	Rowland Intensity	Chr. Int.	Remarks
6291.022 .319	.184	Fe	4	0 0	dr
6298.	.007	Fe	5	.....	bf
6301.560 .871	.718	Fe	7	0 0	dr
6302.560 .861	.709	Fe	5	0 0	dr
6305.873	.878	Sc	0000	1	w
6311.610 .834	.722	Fe	1	0 0	dr
6314.	.876	Ni	4	.....	bf
6315.805 6.241	6.028	Fe	1	0 0	dr
6318.	.239	Fe	6	.....	bf
6322.713 3.091	.907	Fe	4	0 0	dr
6324.759	.....	....	....	0	
6327.615 8.034	.820	Ni	2	0 0	dr
6330.126 .489	.316	Cr	1	0 0	dr
6331.	.067	Fe	2	.....	bf
6335.409 .689	.554	Fe	6	0 0	dr
6336.842 7.341	7.048	Fe	7	0 1	dr
6347.335	.310	....	2N	2	
6355.045 .488	.246	Fe	4	0 0	dr
6358.722 9.045	.898	Fe	6	0 0	dr
6362.579	.560	Zn	1	0	
6362.930 3.264	3.090	Cr, Fe	2	0 0	dr
6364.455 .712	.575	Fe	1	0 0	dr
6369.663	.683	Fe	0	4	
6371.592	.573	Fe	1Nd?	2	
6378.	.468	Ni	2	.....	bf
6380.762 1.140	.958	Fe	4	0 0	dr
6381.836	.844	....	0000	0	
6383.916	.932	Fe	0N	1	w E
6390.706	.715	La	000	1	
6393.	.820	Fe	7	.....	bf
6395.390	.378	Co	00Nd?	0	
6408.606	.587	Co	0000	0	
6411.637 2.070	.865	Fe	7	0 0	dr
6417.120	.133	Fe?	1	3	E
6420.	.169	Fe	4	.....	bf
6421.402 .753	.570	Fe	7	0 0	dr
6430.870 1.251	1.066	Fe	5	0 0	dr
6432.870	.895	Fe?	1	6	
6439.113 .481	.293	Ca	8	1 1	dr
6449.844 50.253	0.033	Ca	6	0 0	dr
6455.218	.230	Co	0N	1	
6455.602 6.043	.820	Ca	2	0 0	dr
6456.597	.603	Fe	3	5	E
6462.	.784	Ca	5	.....	bf
6469.	.408	....	2	.....	bf
6471.677 2.109	.885	Ca	5	1 1	dr
6475.	.846	....	2	.....	bf?
6491.810	.800	Ti	1	0	E
6493.805 4.232	4.004	Ca	6	0 0	dr
6496.978 7.291	7.128	Fe	4	2 2	dr
6498.995 9.371	9.168	Fe	1	0 0	dr
6499.676 6500.096	.880	Ca	4	0 0	dr
6516.310	.311	Fe	2	7	E
6527.198 .656	.444	....	1	1 0	dr
6546.311 .675	.479	Ti-Fe	6	0 0	dr
6554.322 .625	.470	Ti	0	1 0	dr
6555.087	.080	....	0000N	0	
6555.718	.700	....	1N	0	
6559.659 .949	.815	....	0	0 0	dr
6562.299 3.618 .902	.045	H	40	20 10 10	dr
6569.	.460	Fe	5	.....	bf
6586.547	.550	Ni	1	0	
6599.320	.353	Ti	00	0	

sun's visible edge, it seems certain that the results of these observations relate to a very low level in the reversing layer. We are, therefore, quite unable to agree with Mitchell in his conclusion that the spectra taken without an eclipse are at a higher level than the eclipse photographs. In fact the arguments which he adduces, namely, the absence from the Mount Wilson negatives of some strong Fraunhofer lines, which are prominent as bright lines on the eclipse negatives, and, similarly, the strength as bright lines of certain faint Fraunhofer lines point to precisely the opposite conclusion and can be explained only on the basis of a lower level for the photographs taken without an eclipse.

COMPARISON WITH ECLIPSE RESULTS

In the course of the discussion of his admirable eclipse results Mitchell institutes a comparison with the values published by Hale and Adams in their preliminary account of the Mount Wilson observations. From this comparison Mitchell concludes:

1. The eclipse spectrum negatives show twice as many lines as the 60-foot tower telescope photographs.

2. The eclipse spectrum wave-lengths are quite as accurate as those obtained from the tower telescope photographs.

It is difficult to understand the basis for the first of these conclusions unless Mitchell has employed for comparison purposes the violet part of the spectrum in which the visual objective of the tower telescope performs to poor advantage. Certainly in the visual region no such conclusion is tenable on the evidence either of the short region between λ 5111 and λ 5198 previously published, or of the present more complete results. A comparison for the entire region between λ 4800 and λ 5880 shows the following number of bright lines, the double reversals being counted as single lines:

	Mitchell Eclipse	Mount Wilson
Bright lines (measured)	901	894
Dark lines with bright fringes (not measured)	....	133
Total	901	1027

The effect of the difference of level in the reversing layer for the two sets of photographs is seen clearly in these results. Nearly all of the lines with bright fringes on the Mount Wilson photographs appear on Mitchell's negatives as strong bright lines, and the same is true of a large proportion of the Mount Wilson double reversals. A considerable number of strong lines on the eclipse plates do not appear at all as bright lines on the tower telescope plates. This is due evidently to the low level at which the latter were taken. On the other hand, the tower telescope photographs show between one and two hundred lines not seen on the eclipse photographs, essentially all of which are very faint Fraunhofer lines and belong to a low level in the reversing layer. The two series of photographs, accordingly, may be said to represent the spectrum of two sections of the reversing layer at different elevations, to the higher of which the eclipse results belong.

The statement by Mitchell that the degree of accuracy attained for the eclipse and the tower telescope results is about the same is by no means borne out by a detailed comparison. For this purpose we have selected only the single lines common to both sets of measures, omitting all blends and double reversals. A comparison of all of the lines of this character between λ 4800 and λ 5300 gives for the average deviation from Rowland's wave-lengths the following values:

Eclipse Results	Mount Wilson Results
0.029 A	0.011 A

For the entire region between λ 4800 and λ 5880 the results are

Eclipse Results	Mount Wilson Results
0.030 A	0.012 A

It appears, therefore, that the average deviation from Rowland's wave-lengths of the eclipse spectrum lines is about two and one-half times as great as that of the lines from the tower telescope photographs. The well-known very high degree of precision in the relative wave-lengths of Rowland's table necessitates ascribing essentially all of these differences to errors in the determination of the bright-line wave-lengths.

DISCUSSION OF THE RESULTS

In general the results obtained for the chromospheric spectrum agree with eclipse results as regards the elements represented by the largest proportion of bright lines. They differ widely, however, in the matter of the relative intensity of the bright lines as compared with the dark lines of the solar spectrum. With the exception of the hydrogen, magnesium, and sodium lines, and enhanced lines in general, only very few strong dark lines of the solar spectrum are represented by strong bright lines in the chromospheric spectrum taken without an eclipse. Such lines usually remain dark with a faint bright fringe on either edge. As already stated, this is almost certainly due to the low level of the point under observation. The stronger lines of the solar spectrum are accompanied by wings, similar in character to those of the H and K lines of calcium, though very much less in extent and intensity, which are due to the dense vapor at the base of the sun's reversing layer. In observations at the sun's edge these wings appear as faint emission lines, while the central portion of the line, due mainly to gas at a higher level, still remains dark. The phenomenon is in fact just the same as in the case of the well-known double reversals of the calcium and hydrogen lines at the sun's limb.

It seems probable that double reversal is a universal characteristic of all lines in the chromospheric spectrum at a low level, and that failure to observe it in any particular case is due to the faintness of the lines or insufficient resolving power of the spectroscope. Mitchell observed the effect for a few of the stronger lines, even at the level of his eclipse spectra, and several hundred examples are shown in these tables. In most cases the intensities of the two bright components are equal, and when unequal there seems to be no especial preponderance either of the violet or the red component.

The great number of very faint dark lines of the solar spectrum, which are represented by bright lines in the chromosphere, is in excellent accord with St. John's conclusions that such lines are produced at a low level in the solar atmosphere. A large number of these lines in the region λ 5050–λ 5165 may be ascribed to the green carbon fluting. Many others have been identified with

reasonable certainty with lines of cobalt, scandium, titanium, vanadium, and the heavy elements, all of which are very strongly represented in the chromospheric spectrum. It seems probable that a portion of the unidentified lines may be due to the fainter enhanced lines of elements which have as yet been but very imperfectly investigated in this portion of the spectrum.

Some special lines.—The two hydrogen lines which appear in this region are H_α and H_β. Both are strong double reversals in the chromosphere with the components of nearly equal intensity. A peculiar feature is the apparent doubling of the red component of H_α. This is without doubt due to the presence of the strong atmospheric line at λ 6563.763 (the photographs were taken at low sun) which falls upon the center of the bright component and so gives the appearance of a double line.

Of the three helium lines, those at λ 4922 and λ 5048 probably are present, but the first so nearly coincides with a strong La line that it cannot be distinguished with certainty. The D_3 line is the strongest bright line on our photographs, and the scale of the plates is sufficient to make the measurement of its two components possible. The separation found, 0.336 A, agrees closely with the laboratory results.

The D lines of sodium and the b lines of magnesium are very similar in their behavior, being broad double reversals with components of moderate intensity.

A peculiar feature of the results is the remarkable number of faint cobalt lines represented in the chromosphere. In this respect cobalt is to be classed rather with titanium and vanadium than with nickel, iron, and manganese.

The enhanced lines.—It appears from these results that the enhanced lines are of an exceptionally great intensity at a moderate level in the solar atmosphere, just as eclipse observations have shown them to be at a higher level. Upon our photographs they nearly always appear as double reversals, but the separation of the components is considerably less than in the case of arc lines which are doubly reversed. In discussing possible explanations of the prominence of enhanced lines in the flash spectrum Mitchell has referred to the suggestion made by Gale and Adams that it

may be due to the reduction of pressure in the upper portions of the solar atmosphere, laboratory observations having shown that in the case of several elements reduced pressure brings out the enhanced lines more strongly. A second suggestion made by the same writers may also be considered in this connection. It was found that in the spectrum of a spark under moderate pressures comparable with those at the base of the reversing layer the enhanced lines remained bright when the other lines became dark. It would appear probable, therefore, that in the solar spectrum the enhanced lines would be represented by dark lines relatively less intense than would the arc lines. The relative gain in intensity of the enhanced lines when appearing as bright lines in the chromosphere would, accordingly, be due to two causes: first, the actual increase in relative intensity of the enhanced lines due to reduction of pressure; second, the relative weakness of the dark lines in the solar spectrum with which the comparison is made.

Elements of high atomic weight.—The extraordinary prominence of the lines of certain elements of comparatively high atomic weight in the flash spectrum is a well-known feature of eclipse results. Without following Mitchell in his identification of a larger number of lines with those due to praesodymium, samarium, and erbium, we are certainly justified in concluding this behavior in the chromosphere on the part of yttrium, lanthanum, cerium, and probably neodymium.

According to the conclusions of St. John and others, elements of high atomic weight lie at low level in the solar atmosphere. Mitchell concludes from his measurement of the lengths of the arcs of the flash spectrum lines of the rare earths that these do not occur in shallow layers, but rather the reverse. It is, of course, evident that the two sets of results cannot be compared directly if Mitchell is to include among his rare earths scandium, with an atomic weight of 44, and omit barium with an atomic weight of 137. The evidence afforded by the results given here appears to be distinctly in favor of St. John's conclusions. The relative intensities of the bright lines of the heavy elements become greater as we pass from eclipse spectra to the lower level of the observations without an eclipse. Thus if we compare a lanthanum line of solar intensity 1

with an iron line of intensity 1, we find a certain ratio of intensity for the two bright lines in eclipse spectra. In the spectra taken without an eclipse the lanthanum bright line is relatively stronger than in the eclipse spectra. This can hardly be interpreted in any other way than that the radiation of the heavy elements becomes relatively stronger at low levels. The case appears to us analogous to that of the carbon fluting, the individual bright lines of which show the more strongly the nearer the observations are made to the sun's visible edge.

It seems very probable that, as St. John has stated in his discussion of Mitchell's eclipse results, the explanation of the longer arcs found by Mitchell for the rare earths is to be found in the greater intensities of these lines. The average intensity given by Mitchell for the bright lines of the Fe group is 1.07; for those of the rare earths 3.10. There can be little doubt that a bright arc three times as strong as another would on the photographic plate have a considerably greater length. The case is entirely similar to that seen in the laboratory when a photograph is taken of the spectrum of a metallic arc. The strongest lines are the longest even when the lines compared are produced in just the same part of the arc.

Chromospheric wave-lengths and anomalous refraction.—In our determinations of the wave-lengths of the bright lines in the chromosphere we have used as standards of reduction the dark lines of the limb spectrum which appear upon the same photographs. Any differences of wave-length, therefore, are with reference to the lines at the sun's limb, and these, as is well known, are displaced slightly to the red when compared with the center of the sun. In the region covered by the observations this displacement amounts on the average to +0.008 A. Our chromospheric measures give for the average difference in wave-length between 512 identified bright lines and the corresponding dark lines at the limb −0.002 A. If we assume this small difference to be real, the bright lines in the chromosphere, therefore, will be displaced +0.006 A relative to the dark lines at the center of the sun.[1]

[1] In the results given by Hale and Adams the same method was used, and the wave-lengths given were referred to the lines at the sun's limb. Apparently some

The ordinary absorption and emission theory of the origin of the solar lines would explain this result in a very simple way. The chromospheric bright lines are produced at nearly the same level and under nearly the same physical conditions as the dark lines at the sun's limb; hence their wave-lengths should be closely the same. On the whole we should perhaps expect the level of the chromospheric observations to be slightly above that of observations at the sun's limb. If such is the case the cause which produces the displacements of the lines at the limb relative to the center of the sun (which we are still inclined to consider in large part as pressure, in spite of Evershed's recent work on the subject) would operate to a less extent on the bright lines; and we might expect some such small negative difference as is found between their wave-lengths and those of the dark lines at the limb.

In the course of an extensive series of articles Julius has endeavored among other solar phenomena to account for the wave-lengths of the chromospheric lines and for the displacements of the dark lines at the sun's limb on the basis of anomalous refraction and dispersion in the solar atmosphere.[1] The principal feature of the explanation which he adopts is the assumption that the solar atmosphere is honeycombed with irregular density gradients, of which a sufficient number show increasing density outward to overcome wholly or mainly the effect of the well-known regular radial gradient. Most solar observers would desire some evidence tending to indicate the existence of such gradients apart from the necessity of postulating them in order to support the anomalous refraction hypothesis, more especially as they must be essentially permanent in character. If they fluctuated to any considerable

misapprehension has arisen in regard to this matter, as both Julius and Brunt (*Monthly Notices*, **73**, June 1913) appear to consider the wave-lengths as referred to the center of the sun. No explicit statement was made because at the date the results were published the amount of the hypothetical anomalous dispersion effect, due to the regular density gradient, was supposed to be very large, amounting to one-half the width of the lines. The value given by Hale and Adams for chromosphere-limb wave-lengths was $+0.002$ A; the result found here is -0.002 A. We consider this agreement as quite satisfactory in view of the difficulty of the measurements.

[1] "On the Origin of the Chromospheric Light," *Proceedings Amsterdam Academy*, December 23, 1909; "Regular Consequences of Irregular Refraction in the Sun," *Proceedings Amsterdam Academy*, October 28, 1909.

extent, both the displacements at the sun's limb and the wave-lengths of the chromospheric bright lines should show marked systematic variations, and such has not been found to be the case. Assuming the existence of such irregular gradients, however, Julius accounts for the displacements of the dark lines at the limb as follows:

> Indeed rays coming from the limb have, as a rule, accomplished a longer distance through the solar gases than rays coming from the center, and, therefore, were more subject to loss of intensity by the process of incurvation towards the photosphere. The amount of the irregular ray-curving depends on the absolute magnitude of Rm Δm (the refracting power of the mixture of gases), which near the weaker lines of the solar spectrum is sensibly greater with red than with violet light. So the lines must chiefly widen at their red-facing side, in proportion as the opportunity for losing light increases.

That is, the displacements are due to the widening of the lines toward the red owing to the relatively greater loss of red light by anomalous refraction. In this explanation the effect of the regular radial gradient is neglected completely, and in fact in another place[1] Julius states expressly that it would produce displacements toward the violet. Accordingly he is obliged tacitly to assume that the irregular gradients are sufficient to counteract this effect and to give in addition the observed displacements toward the red.

When he passes to the discussion of the chromospheric spectrum Julius again makes use of the irregular density gradients, but in this case he considers they will produce essentially symmetrical bright lines, violet and red light being refracted in nearly equal proportions. As already stated, Julius has not understood the fact that the chromospheric lines are displaced to the red relative to those at the center of the sun by about 0.006 A, since his explanation is intended to account for the absence of any displacement. The photospheric light which is refracted to form the chromospheric lines is supposed to come from near and just beyond the sun's visible edge.

It seems to us very doubtful whether the results found on our photographs can be accounted for by this hypothesis. Bright and

[1] *Astrophysical Journal*, 31, 427, 1910.

dark lines appear on the same negatives and the character of the path through the irregular density gradients must be nearly the same in the two cases. If the displacements of the dark lines at the sun's limb are due to irregular density gradients which tend to produce a loss of light on the red side of the absorption lines and thus widen them toward the red, we must conclude that these gradients would have a marked effect upon the light which forms the chromospheric lines. Accordingly if the photospheric light which is refracted comes from beyond the sun's limb, we should expect a relative loss either of red or of violet light. If the former the chromospheric lines should be displaced to the violet with regard to the dark line at the limb; if the latter it should be displaced to the red. Neither is the case to any marked degree. Apparently the lack of symmetry in refraction which is introduced by Julius to account for the dark line displacements is directly opposed to the chromospheric results. A resort to the regular radial gradient to explain the displacements of the chromospheric lines with reference to the lines at the center of the sun could not be made unless the explanation of the limb displacements were abandoned, since this would require displacements to the violet.

The results of a comparison of the wave-lengths of the chromospheric lines with the corresponding dark lines at the sun's limb are given in Table II. Only such lines have been included as can be identified with certainty, and whose wave-lengths have been measured directly.

TABLE II

Element	No. Lines	Chromosphere—Limb
Fe.	157	−0.001 A
C.	90	−0.002
Ti.	87	−0.004
Co.	42	−0.008
Cr.	35	+0.002
Ni.	32	−0.001
V.	27	−0.003
Ca.	16	0.000
Sc.	13	−0.001
Y.	8	−0.004
La.	5	+0.006
Mean.	512	−0.002

The preponderance of the negative sign in these residuals is rather striking, the only important exception being chromium. Since the average deviation for all of the lines measured amounts to 0.012 A, however, we do not feel justified in considering the slight mean residual of −0.002 A as certainly real.

One other characteristic of the chromospheric lines should be considered in connection with the anomalous dispersion theory. This is the phenomenon of double reversal. Although Julius admits that a portion of this effect may be due to common reversal by absorption, he introduces anomalous refraction and scattering of the light very close to the absorption lines to increase its amount. Two comments may be made in this connection. First, it would seem hardly necessary to bring anomalous refraction into question if the existence of absorption has to be assumed, since laboratory results have shown that it is easy to produce in the spectra of luminous gases just such reversals as are found in the chromospheric spectrum under conditions where only emission and absorption are involved. Second, it is difficult to understand why the double reversals should nearly always be symmetrical, although the refracting power of the solar atmosphere is greater on the red side of an absorption line.

It is a peculiar fact that the advocates of the anomalous dispersion hypothesis admit the existence of essentially all of the phenomena in the sun which are required by those who use the more usual explanation. Thus Julius is willing to admit the presence of ordinary selective absorption and emission to form the central portions of the Fraunhofer lines; double reversal may help to form the double lines in the chromosphere; the Doppler effect is essential in the convection currents required to produce his hypothetical irregular gradients; the existence of pressure can hardly be denied in any gaseous atmosphere; and variations in density are the fundamental basis of anomalous refraction theory. Apparently variations in temperature have not as yet been admitted by Julius, but it is certainly impossible to explain on the anomalous refraction theory the presence in sun-spots of a band spectrum not found at all in the solar spectrum. If the reduction in temperature is once admitted, the spectral characteristics of sun-spots

find not only a ready but a necessary explanation in this fact, as laboratory investigations have shown. Many of the solar applications of anomalous dispersion share this characteristic of being quite superfluous.

Some features of the absorption spectrum on the chromosphere photographs.—The dark lines which appear upon our chromospheric photographs are due to the light from just within the sun's limb and represent the limb spectrum in its most extreme form. In general the changes in the character and intensity of the lines as compared with the center of the sun are those described by Hale and Adams in their publication on the subject[1] some years ago. They are, however, somewhat more pronounced, a result to be expected because of the closer proximity of the point under observation to the sun's limb. In one region of the spectrum, at least, its characteristics deserve a few words of comment.

Between the limits λ 5025 and λ 5150 there are some especially remarkable changes in the spectrum, consisting in the great intensification of certain very faint solar lines, the great weakening of some strong solar lines, and the appearance of several fairly strong lines which apparently are not present in the solar spectrum at all. The changes are such as to modify the spectrum completely and to render its comparison with the usual solar spectrum difficult.

The results of some measurements in this region are given in Table III.

There are some indications of the presence of a banded spectrum in certain portions of this region, especially near λ 5065, λ 5080, and λ 5100. It is possible that this is a trace of the band spectrum of magnesium hydride found by Fowler to be so prominent in the spectrum of sun-spots.

SUMMARY

1. Photographs of the flash spectrum taken with the 60-foot tower telescope show a slightly greater number of bright lines than the eclipse photographs of Mitchell in the same region.

[1] *Mt. Wilson Contr.*, No. 17; *Astrophysical Journal*, 25, 300, 1907.

2. The degree of accuracy in the determination of wave-lengths is between two and three times as high for the photographs taken without an eclipse.

3. The level of the observations is decidedly lower in the case of the tower telescope results.

4. Double reversal is probably a universal characteristic of the bright lines.

TABLE III

Wave-Lengths		Intensity		Character at Limb
Limb	Sun	Limb	Sun	
5034.259	....	1	....	
5034.737	....	2	....	Double
5035.506	.542	3	5	Double
5036.105	.115	2	5	Blend in sun
5037.458	.436	2	000	Blend in sun
5037.869	.885	2	000	
5040.429	.422	1	000	
5043.055	....	1	....	Narrow
5043.218	....	2	....	Narrow
5043.758	.761	1	00	
5044.107	....	1	....	
5056.608	.617	1	000	Narrow
5057.745	{.665 / ....}	2	{0 / ...}	Broad
5061.287	....	1	....	
5076.432	.450	1	3	
5076.595	{.504 / .666}	2	{000 / 0000}	
5086.791	.794	1	0000	
5094.584	.594	1	0	Broad
5097.669	.668	1	0	
5103.148	.142	2	1	
5149.037	.013	2	000	

5. The lines of the elements of high atomic weight are relatively stronger on the photographs taken without an eclipse. This indicates a low level for these elements in the solar atmosphere.

6. The average difference in wave-length between the bright lines of the chromospheric spectrum and the dark lines at the sun's limb is -0.002 A.

7. This close agreement in wave-length does not appear to be in accordance with the anomalous refraction theory of the chromosphere as developed by Julius.

8. Some remarkable differences have been found in the dark line spectrum at the sun's limb as compared with the ordinary solar spectrum. Several new lines appear in addition to great changes in intensity of certain solar lines. There is considerable evidence of the presence of a band spectrum in a portion of the green region of the spectrum.

Mount Wilson Solar Observatory
November 1914

ON THE SIMPLEST FORM OF THE STELLAR INTERFEROMETER FOR DETERMINING THE ANGULAR DIAMETERS OF STARS BY MEANS OF ELLIPTICALLY POLARIZED LIGHT

By S. POKROWSKY

Two pencils of parallel rays, 1, 2, proceeding from any star fall at the angle of complete polarization upon transparent plane-parallel glass plates, I and II. The pencil reflected by the plate I will be completely polarized in the plane of incidence; it will pass through the plane-parallel $\frac{\lambda}{2}$ plate of quartz, the principal section of which is at 45° with the plane of incidence; therefore the plane of its polarization will be rotated through 90° and it will be totally refracted through the plate II and superposed on the pencil 2 reflected by the latter. Since the vibrations in the rays 1 and 2 are coherent, at the instant when they reach the parallel plates as natural light they will give, after coincidence, rays elliptically polarized. On carefully adjusting the interferometer, the field of view will be homogeneous (*teinte plate*) when examined through a nicol. In consequence of the great angles of incidence of the rays 1 and 2 upon the plates I, II, there will be a very great difference of path between them. Consequently the pencil 2 must be previously reflected by the mirrors R and R_1 in such a manner that the path $R\ R_1\ O_1$ will be equal to the path $O\ O_1$. After coincidence the rays follow the ordinary route[1] through the objective, the Wollaston double-image prism W, the astrophotometer p, and finally the ocular O. V, V_1 are two plane-parallel plates of glass to compensate for the difference in path of the rays 1 and 2.

Passing to the evaluation of the optical sensitiveness of the above-described interferometer we can neglect the interference of light in each of the plane-parallel plates I and II; for we suppose that they are sufficiently thick.

[1] S. Pokrowsky, *Astrophysical Journal*, 36, 156, 1912.

Let us estimate the intensity of the beam transmitted by the interferometer to the eye, when natural light of unit intensity is incident upon the plate V; through it will pass

$$\frac{1-\rho}{1+\rho},$$

where

ρ is the coefficient of reflection $=\left(\frac{\mu-1}{\mu+1}\right)^2$

μ is the refractive index for the glass plate V.

The plate I will reflect at the angle of complete polarization

$$\frac{1-\rho}{1+\rho}\times\frac{2r}{1+r}$$

where

$$r=\frac{1}{2}\left(\frac{n^2-1}{n^2+1}\right)^2$$

and n is the refractive index of the glass plate I. Through the plate marked $\frac{\lambda}{2}$ will pass approximately

$$\frac{1-\rho}{1+\rho}\times\frac{2r}{1+r}\left[1-\left(\frac{\mu^1-1}{\mu^1+1}\right)^2\right]^2=\frac{1-\rho}{1+\rho}\times\frac{2r}{1+r}\times 0.95^2\,;$$

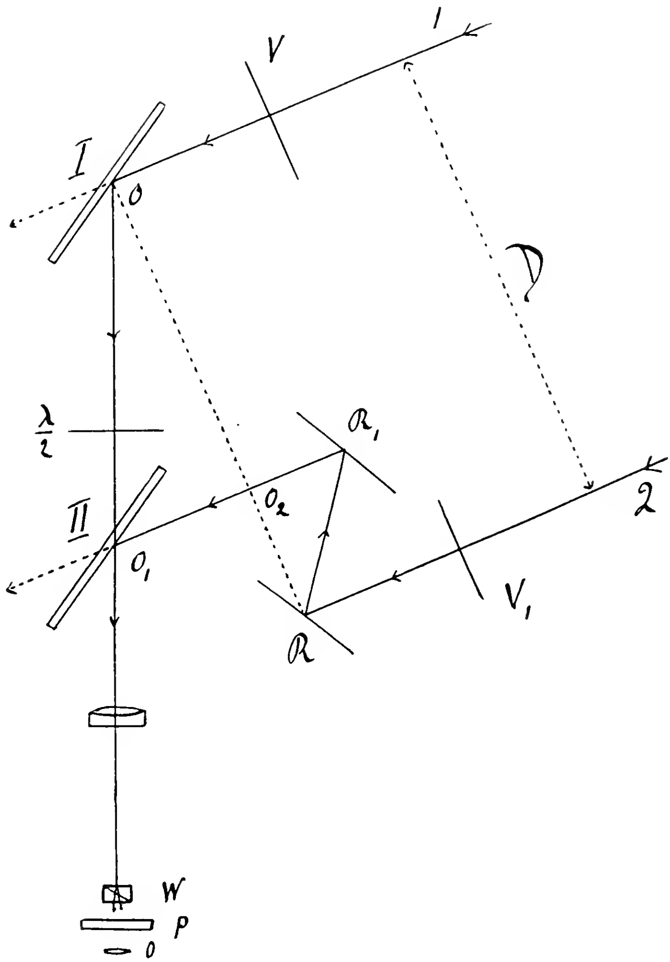
$\mu' \doteq 1.5$ is the average refractive index for quartz. This quantity of rays polarized perpendicularly to the plane of incidence will be totally refracted through the second plate II.

In order to simplify the calculations, we assume that through each of the following eleven surfaces, namely, the three surfaces of the objective; the three surfaces of the double refracting prism; the three surfaces of the astrophotometer, and finally the two surfaces of the eyepiece, passes 95 per cent of the light falling on it, and that moreover about 5 per cent of the light will be absorbed in this apparatus; then the energy that reaches the eye will be

$$\frac{1-\rho}{1+\rho}\times\frac{2r}{1+r}0.95^{14}.$$

This value must be doubled because the plate II also gets the same quantity of luminous energy. Consequently we shall have

$$\gamma = 2 \times 0.95^{14} \frac{1-\rho}{1+\rho} \frac{2r}{1+r}.$$



For the approximate calculation we will take

$$\mu = 1.5 ; \quad n = 1.487.$$

Then

$$\log \gamma = 9.07608.$$

The minimum value of the angular diameter ω to be discovered by the proposed interferometer will be determined by the expression[1]

$$\omega = \frac{4}{\pi} \frac{\lambda}{D} 2.5^{-\left[\frac{K-p}{2} + 1.25 \log \frac{S}{\sigma} \gamma\right]}$$

where

D is the distance between the pencils 1 and 2;
K is the magnitude of a star of the minimum intensity perceptible to the eye;
p is the magnitude of the observed star;
S is the effective area of the objective, determined by the dimensions of the quartz plate;
σ is the area of the pupil of a normal eye; and
γ is the coefficient indicating what fraction of the luminous energy falling on the interferometer reaches the eye.

Assuming

$$\lambda = 5.6 \times 10^{-5} \text{ cm}$$
$$D = 100 \text{ cm}$$
$$k = 6$$
$$S = 10 \times 10 \text{ cm}^2 = 10^4 \text{ mm}^2$$
$$= 4\pi \text{ mm}^2$$
$$\log \gamma = 9.07608$$
$$1'' = 4.84 \times 10^{-6} \text{ in angular measure,}$$

we shall find

for stars of the first magnitude ($p = 1.0$)

$$\omega_1 = 0''.0016$$

for stars of 0.0 magnitude ($p = 0.0$)

$$\omega_0 = 0''.0009;$$

for Sirius ($p = -1.7$)

$$\omega_S = 0''.0006.$$

The above-mentioned values of ω, which can be discovered by means of the described interferometer, were obtained on the assumption that the laws of reflection and refraction of polarized light are expressed very approximately by Fresnel's formulae. As may be seen from the few results which we have at present,

[1] S. Pokrowsky, *op. cit.*, p. 163.

these formulas are confirmed with a precision of 1 to 2 per cent. The condition of the surface-layer of glass and the kind of polish exert a very considerable influence. Lord Rayleigh has shown that only freshly polished glass surfaces give the results in accordance with those of Fresnel; some months later the divergence between theory and practice may amount to as much as 10 to 30 per cent.

Immediate observation shows that rays reflected at the angle of complete polarization will not be entirely polarized in the plane of incidence; but there will be added a small quantity of rays polarized perpendicularly to the plane of incidence; for abbreviation let us name them "residual" rays. The ratio of the amplitudes of the luminous vibrations in these rays to the amplitudes of the luminous vibrations in the rays polarized in the plan of incidence (that is to say, of the principal rays), proportional to the coefficient of ellipticity, was determined by Jamin for a great number of solid and liquid substances; for different kinds of glass this coefficient varies from 0.03 to 0.007.[1] Knowing this coefficient we can easily determine the ratio of the intensities of the two rays which will be exceedingly small since it is proportional to the square of this coefficient.

The residual rays, polarized perpendicularly to the plane of incidence, after traversing the $\frac{\lambda}{2}$ plate will be polarized in this plane; after refraction through the plate II they will be superposed on the analogous rays polarized perpendicularly to the plane of incidence and will therefore produce rays elliptically polarized. Consequently the double refracting prism W will again yield two images of the star exceedingly feeble and coinciding with the first two. The ratio of their intensities will be the inverse of that which existed for the images already examined and formed by the rays polarized in the plane of incidence (that is to say, the principal rays), because the planes of polarization of the two residual rays will be respectively perpendicular to the planes of polarization of the principal rays. In this manner the more intense image formed by the residual rays will coincide with the feebler one produced by the principal rays and will introduce some error in the ratio of the

[1] Winkelmann, *Handbuch der Physik*, **6**, "Optik," pp. 1260–1264, 1906.

intensities of the principal images. Now it is necessary to calculate approximately the intensity (in stellar magnitudes) of the more intense image of the star formed by the residual rays. It will be advisable to employ in the proposed interferometer those kinds of glass which have the smallest coefficients of ellipticity. Consequently before inserting the glass plates, I and II, in the interferometer it will be necessary to determine carefully their coefficient of ellipticity η. I will take

$$\eta=0.0075; \quad n=1.487.$$

If the star under observation is of a magnitude p for the naked eye, when we observe it in the interferometer telescope the more intense of its two images will appear to be a star of the magnitude $\left(p-2.5 \log \frac{S}{\sigma}\gamma\right)$. Since the ratio of the residual amplitudes to the principal ones is equal to

$$\epsilon=\frac{\eta}{2}\sqrt{1+n^2}$$

it will be necessary to take $\gamma\epsilon^2$ instead of γ and the intensity of the more intense image of the star in the residual rays will be of magnitude $p-2.5 \log \frac{S}{\sigma}\gamma\epsilon^2$.

Assuming

$$S=10^4 \text{ mm}^2$$

$$\sigma=4\pi \text{ mm}^2$$

$$\log \gamma=9.07608,$$

we shall find

$$2.5 \log \frac{S}{\sigma}\gamma\epsilon^2=-5.92,$$

that is to say, if the star under observation has a magnitude p for the naked eye, the more intense of its two images formed by residual rays will, when observed in the interferometer telescope, appear to be a star of magnitude

$$p+5.92,$$

but will introduce an error into the ratio of the intensities of the principal images only in the case of Sirius and of the stars of the magnitude 0.0.

In this case, we must accordingly diminish the aperture S of the objective, which will in turn slightly diminish the optical power of the interferometer.

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Petrograd
September 1914

THE DIFFERENT CHARACTER OF SPECTRUM LINES BELONGING TO THE SAME SERIES

By T. ROYDS

It has been generally assumed that the spectrum lines belonging to the same series are similar in character and in behavior under varying experimental conditions. Indeed the similarity in sharpness or diffuseness, or in the direction of unsymmetrical widening, has been a valuable aid in the detection of series relationships in spectra. If, for example, the strong lines of a series were unsymmetrically widened toward the red, the continuation of the series would be looked for in lines widened in the same direction, the widening becoming greater as the higher members were reached. It is therefore of considerable importance to note that there is at least one well-authenticated series in which the character of the lines changes in the course of the series. This is the first subordinate "triplet" series of barium whose lines are given in Table I, column 4. In this series the first members (λλ 5819, 5800, 5777, 5536, 5519, 5424), consisting of a triplet and satellites, are all unsymmetrically widened toward the red; the second members (λλ 4493, 4489, 4333, 4323, 4264) and probably all succeeding are, on the contrary, unsymmetrically widened toward the violet. This is so surprising and important that it is necessary before proceeding farther to make quite sure of our facts. First, there can be little doubt that the first members do really belong to the same series as the higher members; they fit into a formula of the usual type and have the full complement of satellites analogous to the higher members and to the first subordinate series of calcium and strontium. Secondly, the character of the lines seems equally certain. Although previous investigators of the barium spectrum have not noted the character of the first members of the first subordinate series, the reversals of these lines are in my photographs very eccentrically placed on the violet side of the emission line, indicating unsymmetrical widening toward the red. The character

of the second members is obvious and is given by Kayser and Runge as unsymmetrical toward the violet.[1] There is also the evidence of the displacement at the negative pole compared with the center of the arc. I have previously shown that lines are displaced at the negative pole in the direction of their greater widening.[2] Investigating the displacement of the barium lines, I find that all the first members of the first subordinate series are displaced to the red (λ 5536.07 is interfered with by an adjacent line), and all the second members to the violet; this is complete confirmation of their opposite character.

It is interesting to examine also the analogous first subordinate series of calcium and strontium. Of the calcium series the first members are in the infra-red and their character is not known; the second members are quite symmetrical so far as can be judged from the symmetry of their reversals and from the smallness of their displacements at the negative pole of the arc,[3] but the higher members are unsymmetrical toward the violet[4] according to Kayser and Runge[5] and Eder and Valenta.[6] The calcium series is therefore not so extreme a case as that of barium but is still a noteworthy exception to the general run of series. The strontium series is, on the other hand, quite normal if we exclude the infra-red lines whose character is not known. I find that the second members have their reversals slightly eccentrically placed to the red side of their emission lines and that they are displaced to the violet at the negative pole of the arc. These facts indicate that they are unsymmetrical toward the violet and therefore uniform with the higher members whose character has already been observed.[7]

[1] Kayser, *Handbuch der Spectroscopie*, **5**.

[2] Royds, *Kodaikanal Observatory Bulletin*, No. XL.

[3] *Ibid.*

[4] Saunders (*Astrophysical Journal*, **32**, 153, 1910) gives the third members as unsymmetrical toward the *red*. This is probably a mistake. The photograph of Crew and McCauley of the arc in air (*Astrophysical Journal*, **39**, 29, 1914) shows them to be unsymmetrical toward the violet in agreement with Eder and Valenta's observation of the spark lines and mine of the arc lines.

[5] *Handbuch der Spectroscopie*, **5**.

[6] Royds, *Kodaikanal Observatory Bulletin*, No. XL.

[7] Kayser, *op. cit.*, **6**.

In brief, the higher members of the first subordinate "triplet" series of calcium, strontium, and barium are unsymmetrical toward the violet; the first members of the barium series are unsymmetrical toward the red, the second members of the calcium series are symmetrical, while the second members of the strontium series are already unsymmetrical toward the violet.

For convenience of reference I have collected in Table I the lines of the first subordinate "triplet" series of calcium, barium, and strontium.

The chief purpose of the present paper is to point out the importance of determining the pressure-shifts of the first subordinate series of calcium and barium, in which, as we have seen, the character of the lines changes. The interest in these first subordinate series lies in the question whether their lines unsymmetrical toward the violet are, like those of iron, displaced by pressure to the violet, i.e., in the contrary direction to the other lines although belonging to the same series. St. John and Miss Ware, as well as Fabry and Buisson, have shown that the iron lines which widen unsymmetrically toward the violet undergo large displacements to the violet with increased pressure,[1] and Gale and Adams have confirmed this,[2] while those which widen unsymmetrically toward the red undergo large displacements to the red. At present the only evidence available on the point is the difference in the wave-lengths of the calcium arc in air (Holtz[3]) and *in vacuo* (Crew and McCauley[4]). These differences, which are given in Table I, while they should be accepted with some reserve, show that the lines unsymmetrical toward the violet are displaced to the violet by pressure, and the symmetrical lines of the same series, as was found previously by Humphreys, to the red. It has not been doubted until recently[5] that, as discovered by Humphreys, the pressure displacement $\delta\lambda/\lambda$ was constant for all lines belonging to the same series, and this fact has been recommended for the detection of

[1] *Astrophysical Journal*, **36**, 14, 1912; **31**, 111, 1910.

[2] *Ibid.*, **37**, 391, 1913.

[3] *Zeitschrift für wissenschaftliche Photographie*, **12**, 101, 1913.

[4] *Astrophysical Journal*, **39**, 29, 1914.

[5] Swaim, *ibid.*, **40**, 137, 1914.

TABLE I

THE FIRST SUBORDINATE "TRIPLET" SERIES OF CALCIUM, STRONTIUM, AND BARIUM

ORDER IN SERIES	CALCIUM		STRONTIUM	BARIUM
	λ	λ(Arc in Air) −λ(Arc *in Vacuo*)‡	λ	λ
First members.	19916.0	...	...	5819.21 (*ur*)
	19864.6	...	30110.7	5800.48 (*ur*)
	19777.4	...	29225.9	5777.84 (*ur*)
	19507.1	...	27356.2	5536.07 (*ur*)
	19452.9	...	26915.4	5519.37 (*ur*)
	19310.6	...	26024.5	5424.82 (*ur*)
Second members....	4456.81 (s)	+0.011	4971.85 (*uv*)	...
	4456.08 (s)	+ .018	4968.11 (*uv*)	4493.82 (uv)
	4454.97 (s)	+ .016	4962.45 (*uv*)	4489.50 (uv)
	4435.86 (s)	+ .009	4876.23 (*uv*)	4333.04 (*uv*)
	4435.13 (s)	+ .016	4872.66 (*uv*)	4323.15 (uv)
	4425.61	+ .021	4832.23 (*uv*)	4264.45 (*uv*)
Third members.	3645.14*	...	4033.25	...
	3644.86 (*uv*)†	− .003	4032.51 (uv)	4087.53 (u)
	3644.50 (*uv*)†	+ .003	4030.45 (uv)	4084.94 (u)
	3631.10 (*uv*)	− .015	3970.15 (u)	3947.6 (u)
	3630.83 (uv)†	− .010	3969.42	3945.6 (u)
	3624.15 (uv)†	− .001	3940.91 (uv)	...
Fourth members....	3362.42*	...	...	...
	3362.27*	...	...	...
	3361.92 (uv)	− .014	3705.88 (u)	3895.2 (u)
	3350.50*	...	3653.90 (u)	...
	3350.22 (uv)	− .010	3653.32 (u)	3767.5 (u)
	3344.49 (uv)	− .017	3629.15 (u)	...
Fifth members.	...	...	...	...
	3226.26*	...	...	...
	3225.74 (uv)	− .021	3547.92 (u)	3787 (u)
	3215.46*	...	...	...
	3215.15 (uv)	− .019	3499.40 (u)	...
	3209.68 (uv)	− .038	3477.33 (u)	...
Sixth members.	...	...	...	...
	3151.41*	...	...	...
	3150.85 (u)	− .030	3457.70 (u)	...
	3141.29*	...	...	...
	3140.91 (u)	− .062	3411.62 (u)	...
	3136.09 (u)	−0.135	3390.09 (u)	...
Seventh members.....	3101.87 (u)	...	3400.39 (u)	...

(s) denotes symmetrical, (ur) unsymmetrically widened toward the red, (uv) unsymmetrically widened toward the violet, and (u) hazy or diffuse. Those given in italic are new observations; those in roman type are as recorded by other observers.

* Wave-lengths in the arc *in vacuo* by Crew and McCauley reduced to Rowland's scale.

† These lines are given by Saunders as unsymmetrical toward the red, probably by mistake. See footnote on p. 155.

‡ Taken from Crew and McCauley's paper.

series.[1] Judging from the analogy of the iron lines and from the foregoing results for calcium, however, it appears probable that, so far from being constant, the pressure-shift may even be in opposite directions for different lines of the same series.

This brings up the whole question of the relationship between pressure-shift and series. Humphreys found[2] that the pressure-shift ($\delta\lambda/\lambda$) was constant for all the lines of the same series, and that the shifts for the principal, the first and second subordinate series were in the ratio 1:2:4. Although these ratios seem to hold for the majority of cases, about one-third of the total number are exceptions. These exceptions are given in Table II; the mean shifts reduced to λ 4000 at the same pressure for the different series of the same element are quoted from Humphreys' tables. Where data at the same pressure are not available the shift has been calculated from that at a neighboring pressure and is given in parentheses.

TABLE II

EXCEPTIONS TO HUMPHREYS' SERIES LAW

Series	Mean Shift	Ratio	Series	Mean Shift	Ratio
Al {First subordinate.. Second subordinate	50 (40)	1:0.8	Hg {First subordinate... Second subordinate.	70 66	1:0.9
Li {Principal......... First subordinate..	66 (96)	1:1.5	Na {Principal.......... First subordinate*..	73 312	1:4.3
Mg {First subordinate.. Second subordinate	35 45	1:1.3			

* By an unfortunate error or misprint, Humphreys has classed the lines $\lambda\lambda$ 5682, 5688 as belonging to the second subordinate series of sodium instead of to the first, making it appear as though they conformed to his law.

The shifts were reduced to λ 4000 by Humphreys on the assumption that the absolute pressure-shifts are proportional to the wavelength. If the shifts are proportional to some other power of the wave-length than the first, some of these exceptions might be brought into line, but on the other hand new ones would be introduced.

[1] Kayser, *Handbuch der Spectroscopie*, **2**, 327, 579.

[2] *Astrophysical Journal*, **6**, 169, 1897.

Recently Swaim has arrived at entirely different series relationships in studying the pressure-shifts of the zinc lines.[1] He finds that the shifts of the lines in the first subordinate series are *inversely* proportional to the cube of the wave-length, in the second subordinate series *inversely* proportional to the first power of the wave-length, and of non-series lines *directly* proportional to the square of the wave-length. There is therefore no direct relation between the first and second subordinate series.

It seems to me exceedingly probable that all these inconsistencies are due to the existence of a density effect superposed on the true pressure effect. When the arc is placed under pressure there is probably not only an increase in the pressure of the atmosphere surrounding the arc but also an increase in the density of the vapor in the arc owing to a more rapid production of vapor, or other cause. The effect of an increase of density is to displace the unsymmetrical lines in the direction of their greater widening, and by an amount apparently dependent only on the degree of unsymmetrical widening.[2] This might explain Swaim's curious results mentioned above. He noted that the amount of displacement under pressure depended on the diffuseness of the line, and, since the series lines he measured are unsymmetrical toward the red, it seems probable that the large displacements to the red he obtained for the higher and more unsymmetrical members of the series are due, at any rate in part, to increased vapor density.

Many of the anomalous results obtained by Duffield in the arc under pressure are also probably due to density effects. Duffield found that when unsymmetrical lines are reversed the displacement of the reversal falls to half of that of the unreversed line, while the reversals of symmetrical lines remain normally displaced.[3] Now the unsymmetrical lines are those sensitive to density-shift and it would be expected that at the lower density of the absorption line their displacement would be smaller, while symmetrical lines would be unaffected. He also finds that the displacement of a line may have two alternative values at one and

[1] *Astrophysical Journal*, **40**, 137, 1914.

[2] Royds, *Kodaikanal Observatory Bulletin*, No. XL.

[3] *Phil. Trans. Roy. Soc.*, A **208**, 151, 1908.

the same pressure.[1] Duffield says: "Whatever the nature of the disturbing cause, Group III and then Group II [of the iron lines] are most susceptible to it."[2] The lines of Group III, all unsymmetrically widened toward the red, are those most susceptible to density-shift,[3] while the lines of Group II, much widened but not unsymmetrically by pressure, have not been sufficiently investigated. He further says: "On the photographs showing abnormal displacements [approximately twice the normal values], the reversals are more numerous and broader than they are on plates giving normal values";[4] this observation is direct evidence of increased density. I admit, however, that there is no obvious reason why the ratio of the larger displacement to the smaller should be approximately 2:1.

An additional interest for the investigation of the calcium lines under pressure is the question of the behavior of Fowler's series of narrow triplets (λλ 4586, 4581, 4578, etc.). According to Moore[5] the Zeeman effect for these lines is either zero or at least very small, and therefore their pressure displacement would be expected to be small also.[6] It will, however, not be conclusive if they prove to have large displacements in the *arc* under pressure, since these lines are easily displaced by density.[7]

For the elucidation of the relationship between pressure-shift and series, as well as for the solution of solar problems, it seems essential to isolate the pressure effect from the density effect. The means of doing this are not obvious, and the only hope seems to lie in investigating the furnace spectrum under pressure rather than the arc spectrum, for in the furnace the vapor density, dependent on the rate of production and of disappearance of vapor, is almost certainly influenced by pressure to a much less degree than in the arc. All that we know at present is that since the density effect

[1] *Phil. Trans. Roy. Soc.*, A **209**, 216, 1909. [2] *Ibid.*

[3] Royds, *Kodaikanal Observatory Bulletin*, Nos. XXXVIII and XL.

[4] Duffield, *Phil. Trans. Roy. Soc.*, A **208**, 161, 1908.

[5] *Astrophysical Journal*, **33**, 385, 1911.

[6] See King, *Astrophysical Journal*, **31**, 433, 1910; and Humphreys, *ibid.*, **23**, 233, 1906; **26**, 18, 297, 1907; **27**, 194, 1908.

[7] Royds, *Kodaikanal Observatory Bulletin*, No. XL.

is very small for symmetrical lines, their shifts in the arc under pressure are probably due to the pressure only, but that the shifts of unsymmetrical lines are, partly at least, due to density. Evershed suggests to me that the shift to the violet found in the arc under pressure for certain iron lines may be entirely a density effect, and an observation of Humphreys[1] supports this view. It certainly seems probable that many of the laws of pressure-shifts will be modified, and it is hoped simplified, if experiments can be conducted under conditions of constant vapor density. The elimination of density effects in order to obtain true pressure-shifts is one of the most pressing problems for those interested in the displacements in the sun's spectrum.

Kodaikanal Observatory
September 29, 1914

[1] *Astrophysical Journal*, **31**, 459, 1910.

A CRITERION FOR SPECTROSCOPIC BINARIES, WITH AN APPLICATION TO ρ LEONIS

By FRANK SCHLESINGER

It not infrequently happens that an observer of spectroscopic binaries has accumulated a large number of plates of a single star without being able to determine the period or even to decide whether the object is really a binary. This difficulty occurs when the amplitude of the star is small and of the same order as the accidental errors of observation.

The writer has found the following process to be of considerable service in such cases. The method consists in first constructing a frequency-curve for the velocities; this is done by dividing the total range exhibited by the measured velocities into successive groups of equal extent, say 3 km each, and then counting the number of velocities that fall within these groups. Regarding these numbers as ordinates, we plot them and join the ends by a smooth curve, which is the frequency-curve for these velocities. We next compare the shape of this curve with that of the well-known error-curve. If the two are reasonably the same, we conclude that the star is not a spectroscopic binary (within the limits that our measurements are capable of defining), but that the differences in the measured velocities are errors of observation. This conclusion entails the assumption that the orbits of all binaries, whatever their shape and situation may be, will yield frequency-curves for the velocities that differ decidedly from the error-curve. This assumption accords with the facts, for although the frequency-curves differ greatly from each other for various types of orbits, there is no type that corresponds to the error-curve.

If the frequency-curve is such as to indicate that we are not dealing solely with errors of observation but that the object is really a binary, we can in general go somewhat farther and infer something as to the character of the orbit. For this purpose we divide orbits into four classes:

1. *Circular orbits.*—In this case the velocity-curve (that is, the curve that shows the relation between the velocity and the time)

is a sine-curve as drawn in Fig. 1. Let us divide the total range of velocity into ten equal parts as indicated by the horizontal lines. For a large number of observations the frequency with which any

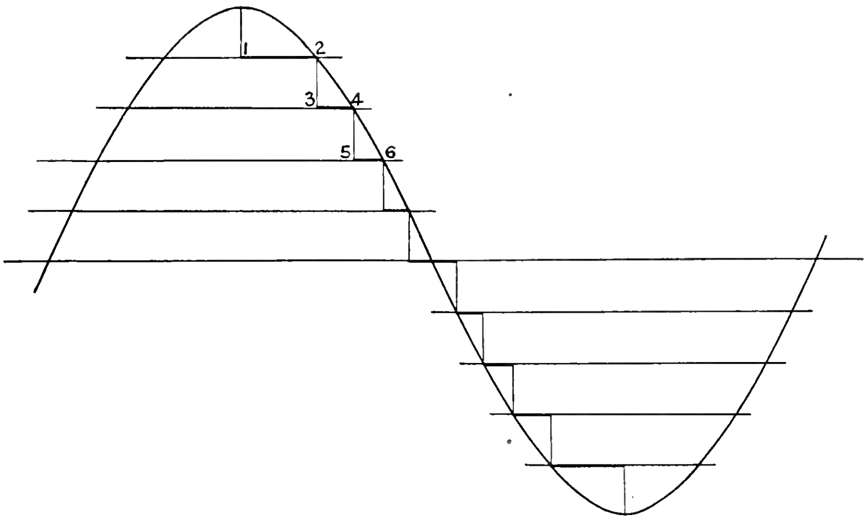


FIG. 1.—Velocity-curve for a circular orbit

velocity occurs will be proportionate to the time-interval during which the velocity is between these successive limits. Consequently the frequencies are proportionate to the lengths (1, 2),

FIG. 2.—Frequency-curve for a circular orbit

(3, 4), (5, 6), etc. The frequency-curve is the full line in Fig. 2. Making allowance for the presence of accidental error, the kind of curve that we should expect in practice is shown by the dotted line.

For a circular orbit, then, high and low velocities occur with the maximum frequency, while intermediate velocities occur more rarely.

2. *Eccentric orbits with periastron near the descending node.*—This velocity-curve is shown in Fig. 3. The frequencies are proportional to the lengths (1, 2), (3, 4), etc., and the frequency-curve therefore has the general appearance shown in Fig. 4. High velocities greatly predominate in number, while low and intermediate velocities are rare.

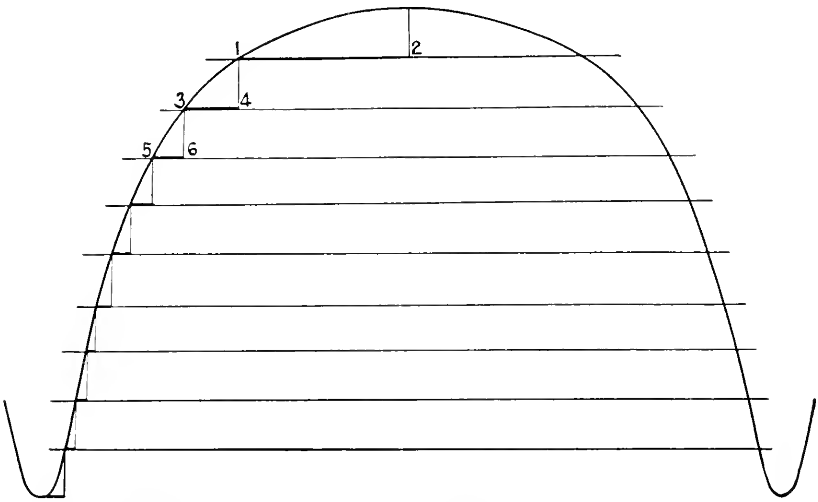


FIG. 3.—Velocity-curve for eccentric orbit with periastron at descending node

3. *Eccentric orbits with periastron near the ascending node.*—The velocity-curve for this case can be obtained by inverting Fig. 3, and the frequency-curve by turning Fig. 4 end for end. Low velocities predominate, while high and intermediate velocities are rare.

4. *Eccentric orbits with periastron removed 90° from the nodes.*—Fig. 5 shows the velocity-curve for the case in which periastron follows the ascending node by 90°, or, expressed in accordance with the usual conventions, the longitude of periastron is 90°. The frequencies are now proportional to (1, 2), (3, 4)+(5, 6), (7, 8)+(9, 0), etc. The corresponding frequency-curve comes out prac-

tically the same as Fig. 2. For the opposite kind of orbit, that in which the longitude of periastron is 270°, the velocity-curve can

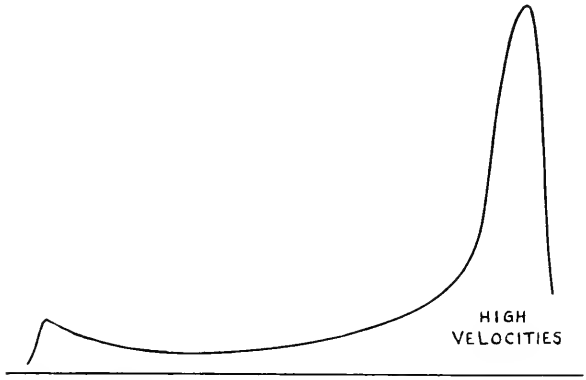


FIG. 4.—Frequency-curve for eccentric orbit with periastron at descending node

be obtained by turning Fig. 5 end for end, but the frequency-curve is precisely the same. The present criterion does not enable us to

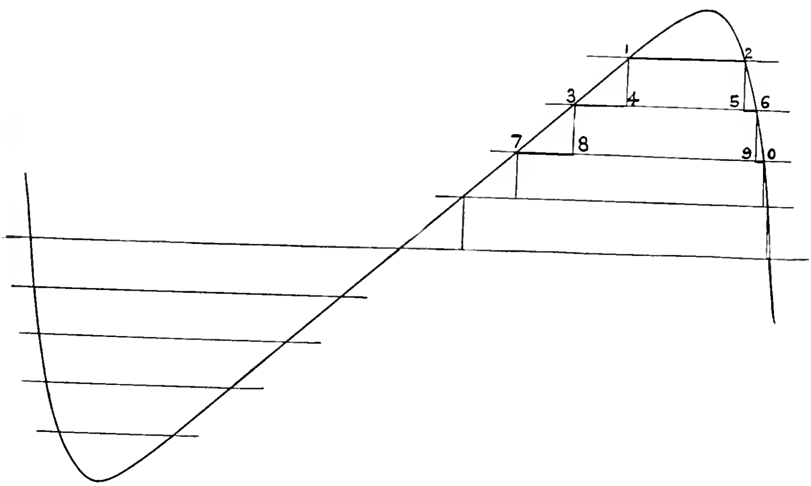


FIG. 5.—Velocity-curve for eccentric orbit with periastron at 90°

distinguish between these two orbits, nor to distinguish either of them from a circular orbit. Consequently if we obtain in any particular case a frequency-curve like that in Fig. 2, we infer either

that the orbit is circular or else that the longitude of periastron is about 90° from the nodes.

The writer has applied this criterion to advantage in a number of cases; the most instructive of these is that presented by ρ Leonis ($10^h 28^m$, $+9°49'$), a helium star of the fourth magnitude. This star was first suspected of varying in its radial velocity by the Lick observers, but later it was removed from their list of spectroscopic binaries. In 1910 and the two following years Mr. Harper obtained sixty-five plates of the star with the single-prism spectrograph of the Ottawa Observatory. From these he was unable to decide whether the object is a spectroscopic binary, though he inclines to believe that it is. Not succeeding in finding a period that will fit the observations, he has (in a very commendable spirit) published[1] his measures and the other data for the plates, in order that they may be available to other astronomers.

The measured velocities for these sixty-five plates range from +26 km to +57 km. Dividing them into groups with 3 km limits, and counting the number of velocities that fall within each group, we have:

3	velocities	less than	+30 km		
1	velocity	between	+30 km	and	+33 km
3	velocities	"	+33	"	+36
6	"	"	+36	"	+39
8	"	"	+39	"	+42
14	"	"	+42	"	+45
20	"	"	+45	"	+48
6	"	"	+48	"	+51
3	"	"	+51	"	+54
1	velocity	between	+54	and	+57

The frequency-curve that these numbers give is very different from the error-curve. The greatest number of velocities is found between 45 km and 48 km; below these limits there are altogether thirty-five velocities, while above them there are only ten. We conclude that the star is a spectroscopic binary, and furthermore, since this is an example of what we have described as Case 2, that the orbit is one of high eccentricity with the longitude of

[1] *Publications of the Dominion Observatory*, 1, 337, 1914.

periastron (always reckoned from the ascending node) in the neighborhood of 180°.

If this conclusion is correct, a search for the period would most profitably concern itself only with the lowest velocities. Computers of the orbits of spectroscopic binaries are only too familiar with the difficulty in deciding upon which branch of the curve certain velocities belong, when they are trying to ascertain the period. In the present instance this additional difficulty is removed for the lowest velocities, because these must all be in approximately the same phase, as the reader may see by referring to Fig. 3.

Acting upon this hint, I examined the seven velocities lower than +33 km and found that with the period 12.28 days all seven of them fall within a day of the phase 7.3 days, the date of Mr. Harper's first plate being taken as the initial epoch. Furthermore, I found that not one of the highest eighteen velocities falls within these same limits. There can therefore be no doubt that 12.28 days is a close approximation to the period of this binary.

An inspection of the velocity-curve obtained by plotting the Ottawa results on this period enables us to estimate that the semi-amplitude of oscillation is 10 km or more, that the eccentricity is probably greater than 0.5, and that the longitude of periastron probably lies between 150° and 210°. Closer approximations to these elements could doubtless be deduced from the present material by a thorough computation, but this work would hardly be repaid. Now that the period of the binary has been established it is possible to secure additional plates near periastron, and these are indispensable for a more accurate determination of the orbit.

In conclusion I may remark that the present criterion is of wider application than the title of this paper implies. For example, we may by its help sometimes infer the character of the variations in the light of a star before the period has been determined. The test is in fact applicable to all periodic phenomena.

Allegheny Observatory
University of Pittsburgh
November 21, 1914

Minor Contributions and Notes

THE SOLAR PROMINENCE OF OCTOBER 19–21, 1914

The first observation of this prominence with the Rumford spectroheliograph was made on October 19 at 3^h10^m G.M.T. On account of thin, hazy clouds covering the sky the prominence is only very faintly visible as a pyramid about 120″ high, its base in position angle 239–249°. On October 20 seven photographs, made in the light of the calcium line H, were obtained. Two of these are shown in the accompanying plate. On October 21 thirteen plates of this prominence were obtained between 3^h17^m and 5^h35^m. The last photograph shows the floating cloud at an elevation of 430″ or 308,000 km, but so faintly that no attempt has been made to reproduce it here. A plate exposed at 5^h41^m shows only the low eruptions near the bases of the former prominence and another plate exposed at 7^h19^m shows hardly a trace of activity on this portion of the sun's limb. Although the prominence occurred on the west limb of the sun and its base must have been on the visible hemisphere for at least one of the three days of observation, there is no indication of any eruption shown on spectroheliograms of the disk which were also taken in the H line of calcium.

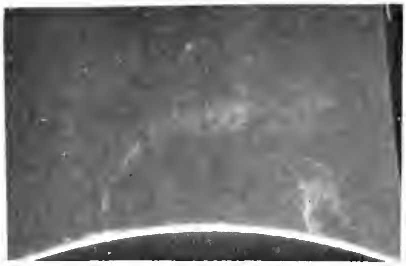
The change in the character of the prominence from quiescent on October 20 to violently eruptive on October 21 is perhaps its most interesting feature. As a result of the rapidity of the changes and the general faintness of structure, identification of measurable points from one plate to the next is uncertain.

The photographs reproduced in Plate V are reduced about 22 per cent from the originals. The diameter of the sun's image on the scale of the reproductions is 142 mm.

From 5^h40^m to 7^h27^m G.M.T. the low prominence at the extreme right has drifted tangentially to the sun's limb about 50,000 km at a rate of 7.6 km per second. The current 20,000 km higher up is in the other direction, as indicated by the main prominence. If the

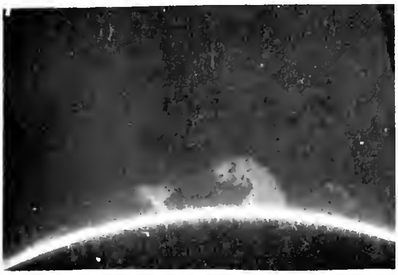
PLATE V

a)



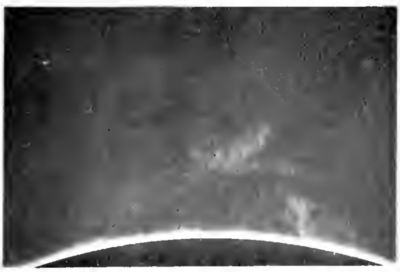
e)

b)



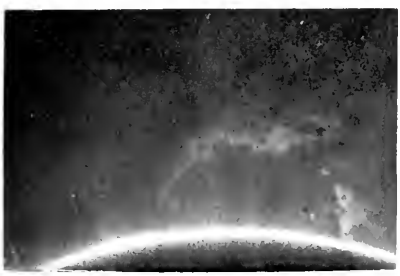
f)

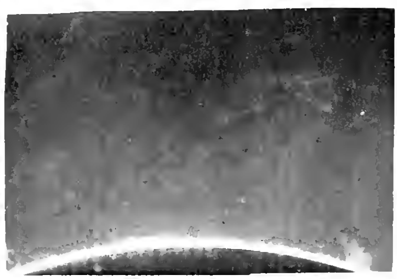
c)



g)

d)





h)

THE SOLAR PROMINENCE OF OCTOBER 19–21, 1914

a)	20 October	$5^h 40^m$ G.M.T.	e)	21 October	$4^h 17^m$ G.M.T.
b)		7 27	f)		4 40
c)	21 October	3 17	g)		4 57
d)		3 56	h)		5 07

negatives in the series taken on October 21 be superposed consecutively on that exposed at $3^h 17^m$, using the base of the main eruption as the fiducial point, the cloud forms are seen to retreat radially from a point on the limb of the sun about 100,000 km toward the left from the base. From $3^h 56^m$ to $4^h 17^m$ this motion of the left-hand base of the arch was 7 km per second tangentially. From $4^h 17^m$ to $4^h 49^m$ it was 26 km per second. From $3^h 56^m$ to $4^h 17^m$ the motion of the densest part of the floating cloud away from the limb was 18 km per second. Two condensations are visible at $4^h 17^m$ in the left stem of the arch. They are faintly visible at $4^h 49^m$. Their velocity meantime was 31 km per second in the normal to the limb and 17 km per second in the line joining them with the base of the main eruption. In the same interval the crest flowing toward the right from the main stem had a velocity of 21 km per second. The total area inclosed by the enormous arch shown at $4^h 49^m$ exceeds 145 times the total area of the earth.

20 October	$5^h 40^m$ G.M.T.	21 October	$4^h 17^m$ G.M.T.
	7 27		4 49
21 October	3 17		4 57
	3 56		5 7

OLIVER J. LEE

ON THE NON-EXISTENCE OF THE LINE OF WAVE-LENGTH 6708 A IN THE ARC SPECTRUM OF CALCIUM

According to Meisenbach,[1] the line spectrum of calcium contains a line of wave-length 6708.157 A, and this line is also listed as present in the spectrum of calcium in Kayser's *Handbuch der Spectroscopie*.[2] What seems to be the same line, of wave-length 6708.13 A, was found by Hale and Adams[3] to be present in the spectra of sun-spots. For the same line in the spectrum of the sun they give the wave-length as 6708.18. However, while they class this as a calcium line, they state[4] that "it is not certain that this line is due to calcium, as it appears strongly on plates of several other elements." It is well known that a line of the wave-length

[1] *Zeitschrift für wissenschaftliche Photographie*, **6**, 258, 1908.

[2] *Ibid.* [3] *Astrophysical Journal*, **25**, 31, 1907. [4] *Ibid.*

given is the strongest line in the spectrum of lithium, and since in preliminary experiments with ordinary calcium salts it was found that the relative brightness of this line and the calcium line λ 6717.940 varied greatly, it was considered that the supposed presence of the line λ 6708 in the spectrum of calcium might be due entirely to the presence in the calcium salts of lithium in varying amounts as an impurity. This was confirmed by photographing the arc spectrum of gypsum prepared by a diffusion method, when it was found that the line became extremely faint, and not materially brighter than the same line as given by the carbon electrodes themselves. Before use these carbon electrodes had been repeatedly washed in concentrated hydrochloric acid and distilled water, but this was not sufficient to remove all of the lithium originally present in the carbon electrodes. It was found, however, that by allowing the arc to burn for about half an hour before putting in the calcium salt, the lithium could be entirely removed.

When carbon electrodes which did not give a trace of the line λ 6708 were used, it was found that a sample of Kahlbaum's analyzed calcium carbonate gave in the arc no trace of this line, which therefore does not belong in the spectrum of calcium.

This line was then measured in the arc spectrum given by lithium chloride, by comparison with Rowland's value for the calcium line λ 6717.940, and was found to have a wave-length of 6708.040 A. No line near enough to be mistaken for this line appears in Rowland's *Table of the Solar Spectrum Wave-Lengths*. In order to make a better comparison with Rowland's table, the arc was inclosed, and the pressure-shift of the line λ 6708 with respect to λ 6717 was determined from 9 to 167 cm of mercury. The pressure-shift per atmosphere was found to be -0.048 A. Assuming the pressure-shift to be a straight line function, and that the pressure on the sun where such light might be emitted is 5.5 atmospheres, which is according to Fabry and Buisson,[1] it was computed that the wave-length of this line in the solar spectrum, if lithium were present in the sun, would be 6707.782 A. This again is too far from any line given in Rowland's table to be mistaken for it. The nearest lines given in Rowland's table are

[1] *Comptes rendus*, **148**, 688, 1909.

$\lambda\lambda$ 6707.695 and 6708.176. Since this is by far the strongest line in the spectrum of lithium, these results furnish additional evidence that lithium is not present in the sun.

According to Kayser the lithium line λ 6103.77 is of the same brightness as the line λ 6708, but it was found that the commercial calcium chloride used in this laboratory gave no trace of the line λ 6103.77 on plates which showed λ 6708 very distinctly. This shows that the line λ 6708 is a very much more sensitive indicator of lithium than the other.

It was believed by Ramsey that lithium was a decomposition product of copper. Photographs were taken of the arc spectrum of copper using electrolytic copper for electrodes in the first case and bars sawed from samples of Lake Superior native copper, in the second. In the former the lithium line λ 6708 was observed but not in the latter. This is evidence that lithium is a foreign impurity and not a decomposition product.

In conclusion, the writer wishes to thank Dr. H. G. Gale and Dr. W. D. Harkins of this University for their inspiration and assistance in this investigation.

H. G. Woodward

University of Chicago
August 1914

Reviews

The Reform of the Calendar. By Alexander Philip. London: Kegan Paul, French, Trübner & Co., Ltd. (New York: E. P. Dutton & Co.). 8vo, pp. 127. $1.50 net.

This is a thoroughly sensible presentation of the arguments in favor of the amendment of some of the absurdities of our present calendar. These defects, both direct and indirect, are clearly pointed out, and the leading proposals for reform are given. By excluding New Year's Day from monthly and weekly enumeration, and by evening up the months so that each quarter shall have 91 days, in the order 31, 30, 30, the year would always begin on the same day of the week, and each quarter would similarly have a fixed week day for its commencement. Leap Year would be cared for by having the extra day fall between June 30 and July 1, without being counted as a day of the week, and being known only as "Leap Day." The advantages of a fixed date for Easter, which greatly affects manufacturing interests and the schedules of railways and of all educational institutions, are explained. The Congress of Chambers of Commerce of the world unanimously adopted in London in 1910 resolutions in favor of a fixed international calendar and a fixed date of Easter, which resolutions were reaffirmed by the next Congress held at Boston in 1912.

As modern astronomy touches practical life at none too many points, it might be regarded a duty by astronomers to give their influence in favor of a more rational calendar. The adoption of such a reform could not be better emphasized than by having it go into effect on the first day of the year following the conclusion of peace after the horrible war now devastating Europe.

E. B. F.

THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME XLI APRIL 1915 NUMBER 3

AN OPTICAL PERIODOGRAPH[1]

By A. E. DOUGLASS

In a preceding article[2] the writer described a photographic device for producing a "periodogram" which promised to have some of the usefulness predicted by its proposer, Professor Arthur Schuster. By its aid the coarser and more persistent fluctuations of value in a series of measures, such as annual sun-spot numbers or rainfall, can be observed with a slight expenditure of mechanical work in plotting, but without mathematical analysis. The experience with that device and with the peculiar variations in the sun-spot numbers strongly indicated the need of more rigid analysis. It became evident indeed that not merely every possible period should be tried as a whole but that every period should be tried in detail and its varying application throughout the entire series of observations made evident and measurable. This need of detailed analysis was in the last article met to a slight extent by a system of multiple plotting in which the solid white curve was repeated many times parallel to itself with regular and equal dark intervals between. Each repetition of the curve also was displaced by a constant amount to one side of its predecessor. Periods then showed themselves by rows of crests which immediately became evident.

[1] Prepared with assistance from the Elizabeth Thompson Science Fund.

[2] *Astrophysical Journal*, 40, 326, 1914, in which a number of references are given.

Secondary variations showed by lack of straightness in these rows. Any individual row was in effect nothing more than a plot of departures from the constant period represented in the diagram by a vertical line. The duplication of rows assisted the eye in judging of straightness. In the recent improvements of the apparatus this duplicate plotting has been made entirely automatic.

PROCESS

The curve is rendered a solid white area on a black background (or the reverse). The white area showing is limited if necessary by long, straight black mats. To a large camera lens

1760—

1905—

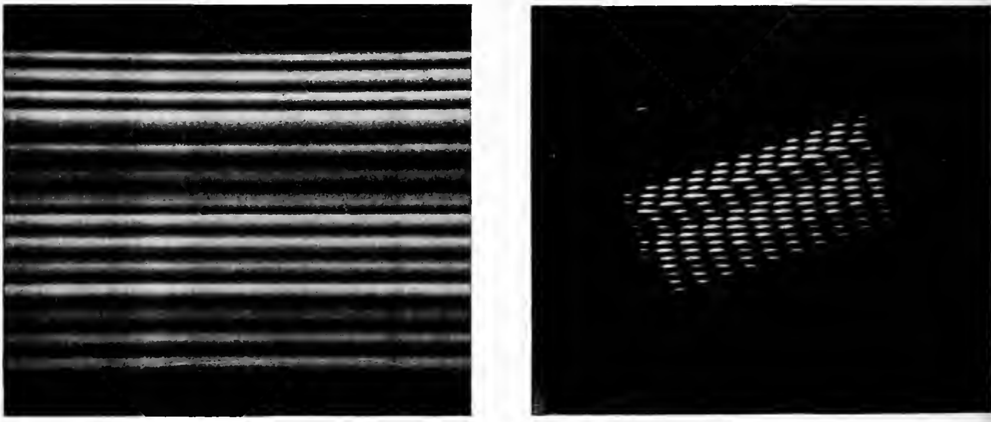


FIG. 1.—"Sweep" of sun-spot numbers and analysis of same by the optical periodograph, showing variations in the period from less than 10 years to nearly 14. Variations are indicated by lack of straightness in the vertical rows.

a cylindric lens is added, by which, in place of a simple image, the curve at the focus is swept or spread across the field, producing a large number of parallel lines, each one proportional in intensity to the height of its corresponding point in the curve (see Fig. 1). Any straight line whatever in any direction across this "sweep" truly represents the original curve, not as a rising and falling line, but in varying light-intensity. A plate with equally spaced parallel opaque lines called the analyzer or analyzing plate is placed in the plane of this "sweep." When the analyzer is turned at a

small angle to the lines of the sweep, each transparent line shows the full curve in its varying intensities. These numerous reproductions are all parallel to each other, separated by equal dark lines, and each one is displaced longitudinally with reference to its neighbors (thus presenting the characteristics of the multiple plot). By twisting the analyzer with reference to the sweep, while the two remain in parallel planes, different periods are tested; for as the analyzer twists, each reproduction varies in respect to its length and its displacement from its next adjoining neighbors, above and below. When a period is formed, it shows itself by rows of dark and light spots in alignment more or less perpendicular to the analyzing lines, as in Figs. 1 and 5. These light and dark rows are analogous to interference fringes and are identical with the elaborate but provokingly useless designs on a wire screen in front of its reflection in a window or with the parallel fringes when two sets of parallel lines are held at a slight inclination to each other.[1]

APPARATUS

The curve is now usually reproduced by preparing a narrow strip of tracing-cloth of barely sufficient width to cover its variations. This is pinned over the curve and all area between the curve and one edge of the cloth strip is painted opaque. The strip is then mounted in a narrow horizontal opening in the window and slightly indirect illumination applied so that the translucent parts give out full and even light.

A stand on casters carries the remainder of the apparatus, whose distance from the curve may thus be varied from 3 to 50 feet. A 6-inch stereopticon lens of $1\frac{1}{2}$-inch aperture casts an image of the curve, about 1 inch in length. Between the curve and the lens and almost in contact with the latter the cylindric lens is inserted with axis parallel to the curve. This lens is concave, of 5-inch focus, and cut 1 inch wide in line with the axis and $1\frac{1}{2}$ inches in length at right angles to the axis. The concave side faces the

[1] W. H. Roever has used somewhat similar interference patterns to illustrate very beautifully certain lines of force (*Bulletin of the Mount Weather Observatory*, 6, 195).

curve. In mounting this lens, about $\frac{1}{8}$ inch is cut off from each dimension.

In the focus of the lens, which may be called the analyzing field, is placed the analyzing plate. It is mounted in the center of a circular disk which rests on wheels and rotates about its center. Four different plates have been made to meet different requirements, the spacing from center to center of the opaque lines being respectively about 0.5, 1.0, 2.0, and 4.0 mm. (It would be well to have intermediate spacings of about 0.7, 1.4, and 2.8 mm in addition.) Considerable difficulty was experienced in making these plates. They are preferably on glass with strong contrast between the opaque and transparent parts. An unexposed dry plate was cleared by a hypo bath and dried. India-ink lines on the film were tried but proved not satisfactory as they were very difficult to produce with perfect regularity and in addition quickly cracked. The grating was finally produced by photographing a 10-foot sheet of co-ordinate paper whose face was covered by line after line (165) of black gummed paper. The co-ordinate lines permitted the spacing to be done with sufficient exactness. The width of the transparent space was throughout three-tenths of the distance from center to center (except in the 4 mm lines when the transparent part is only 0.21; a still smaller space would probably be advantageous). This was carefully photographed by a good lens at three different distances. Two glass prints were made from each negative and then each pair mounted face to face so as

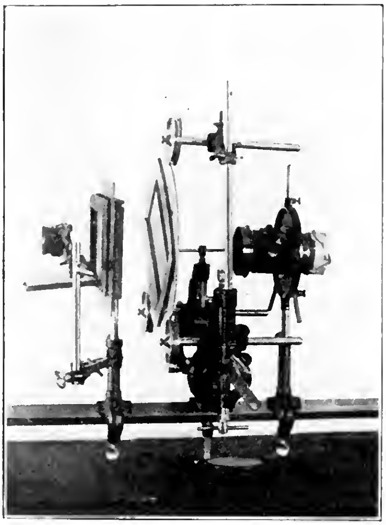


FIG. 2.—Analyzing parts of apparatus with which illustrations in this article were made. From right to left the parts are: cylindric lens, projecting lens, analyzing plate, camera-back and eye-lens. In photographing, the camera-back is moved close to the analyzing plate; in measuring periods, it is replaced by a small position micrometer.

to give great density in the opaque parts. These final plates are 4×5 inches in size and can be interchanged in the rotating disk. Back of the analyzing plate is mounted an eye-lens for visual examination. This lens is about 1 inch in diameter and of 3 inches focus. When a photograph is desired, a camera-back using a $3\frac{1}{4} \times 4\frac{1}{4}$ plate and holder can be put close to the analyzing plate. This arrangement is shown in Fig. 2; the plate-holder, however, in the photograph is moved back a few inches so as not to hide the analyzing plate.

In order to measure the position angle of fringes and obtain other data needed for calculating any period indicated, a small position micrometer can be substituted for the camera-back behind the analyzing field. To get the field reproduced in the plane of the micrometer threads a 3-inch converging lens of 10 or 15 inches focus is placed in or close to the field. This brings the bundle of rays within the compass of a small short-focus lens immediately in front of the micrometer which casts an image of the field in the plane of the threads. Thus the position angle and separation of fringes may be measured, together with the scale of the image of the curve, the spacing of the analyzing lines, and the angle between the analyzing lines and the sweep-lines of the curve. These data are more than are needed to determine the period. Indeed the separation of the fringes may be used as an extra check upon the period found; however, it is not as sensitive as the position angle of the fringe.

Fig. 2 shows the analyzing parts of the periodograph mounted as above described and constructed of ordinary laboratory standards. The only parts at all out of the ordinary are the cylindric lens, which may be obtained at a wholesale optician's, and the analyzing plate.

THEORY

The formula for the period is very simple.

Let y = length of curve in years or other time unit employed
l = length of curve image in cm or other unit of length (across sweep)
s = spacing center to center of analyzing lines in unit of length

Then

$$\frac{l}{s} = \text{number of lines in curve when lines are parallel to sweep}$$

$$\frac{ys}{l} = \text{number of years in 1 line when lines are parallel to sweep}$$

Now taking analyzing lines $\overline{aa'}$ and $\overline{bb'}$ in Fig. 3 as horizontal and letting the sweep be inclined at a small angle δ with the analyzing

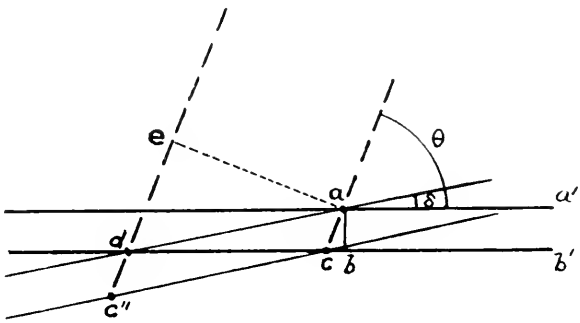


FIG. 3

lines, the number of lines required to cross the sweep in the direction *ab* will be increased and hence the value in years will be decreased; hence

$$\frac{ys}{l} \cos \delta = \text{years per line from } a \text{ to } b$$

If the fringe is perpendicular to the analyzing lines, its period is the distance $\overline{ab}$ in years and we have for this special case:

$$p_1 = \frac{ys}{l} \cos \delta$$

If, however, the fringe takes some other slant as the direction $\overline{ac}$, making the angle θ with the analyzing lines, then the period desired is the time in years between a and c. That equals the time between a and b less the time from b to c. Now $\overline{bc}$ in years would equal $\overline{ab}$ cot θ except for the fact that the horizontal scale along $\overline{bc}$ is greater than the vertical scale along $\overline{ab}$ in the ratio $\frac{\cos \delta}{\sin \delta}$ and

therefore a definite space interval along it means fewer years in the ratio of $\frac{\sin \delta}{\cos \delta}$. Hence we have:

$$\overline{bc}\text{ (in years)}=\overline{ab}\text{ (in years)} \tan \delta \cot \theta$$

or

$$P=p_1(1-\tan \delta \cot \theta)$$

The period thus worked out for Fig. 5*a* is:

$$P=1.91-0.41 \cot \theta$$

and for Fig. 5*b*

$$P=3.87-1.01 \cot \theta$$

The separation of the fringes needs to be known at times in order to find whether one or more actual cycles are appearing in the period under test, as in Fig. 5*b*. In Fig. 3

$$\overline{ab}=s$$

$$\overline{ad}=\frac{s}{\sin \delta}$$

$$\overline{ae}=\frac{s \sin (\theta-\delta)}{\sin \delta}$$

which is the width required.

RANGE OF PERIODS COVERED

There are three ways of testing different periods, namely, twisting the analyzer, changing the scale of the analyzer, and changing the scale of the sweep. The first is a very sensitive method; a large angular change, say 45°, covers a relative range of 100–143. The next size of analyzing plate then carries it from 200 to 286 leaving untested the gap between 143 and 200; hence one sees the advantage of an intermediate size to cover this range. As it was, the gap was covered by moving the lens and the plate on its roller stand which changes the scale of the sweep. Thus twisting the analyzer covers only a short range, but change of scale, whether of the analyzer or of the sweep, may be made to cover any desired range whatever. These two offer excellent checks on each other and should both be used.

SUGGESTIONS FOR PRODUCING A PERIODOGRAM

There appear to be several ways of producing a periodogram, all of which, however, use an additional camera with cylindric lens, a slit in the focal plane, and a plate-holder moving past it by clockwork, after the method described in the preceding article. If the desired range is not great, such prints as in Fig. 5 may be used as the source of light, mounted to rotate by clockwork about a central axis. Or the camera and appurtenances may be mounted in place of the camera-back in Fig. 2 and made to take a photograph as the analyzing plate is turned. The best suggestion, however, is to mount the camera as just described and then take the photograph while changing the scale of the "sweep" through a large range by varying the distance between the mounted curve and the projecting lens. This involves changing the focus of the projecting lens at the same time, which is less simple but not impossible. In this way any desired range would be covered in an instructive and convenient manner. In the author's opinion the most valuable use for the full periodogram will be its aid in presenting results to the reader. Although it may not tell the whole story, yet it covers a large field in a very small space.

A PRACTICAL APPLICATION OF THE PERIODOGRAPH

A period of about 25 months was observed over the eastern and central states by Clayton in 1884–1885[1] in rainfall for the preceding decade. It did not persist and the investigation of it was held in abeyance. Recently a periodic variation in eastern temperatures ranging from 16 to 38 months was studied by Arctowski,[2] who identifies it with the period found by Clayton and entertains the idea that a period may vary. More recently the writer suspected a short period in growth of vegetation both in America and in Northern Europe. It seemed to show in the annual growth of trees in many regions but appeared especially marked in Central Sweden, and only somewhat less so in the Vermont region. The period or "seesaw" indicated by the trees was either 21 or 28 months. In order to distinguish between these alternatives

[1] *American Meteorological Journal*, **1**, 130, 528; and conversation.

[2] *Bulletin of the American Geographical Society*, **45**, 120, 1913.

the rainfall near Windsor, Vermont, was compiled[1] from neighboring records and investigated with the periodograph. All possible periods were tested, but those shown in Fig. 5 were by far the most promising. These diagrams indicate a mean result of about 28 months as the predominating period, but show that this value is not perfectly constant. If this were constant the fringes would be straight. Instead of that the whole fringe is slightly displaced near the center for a considerable period of time. This result of

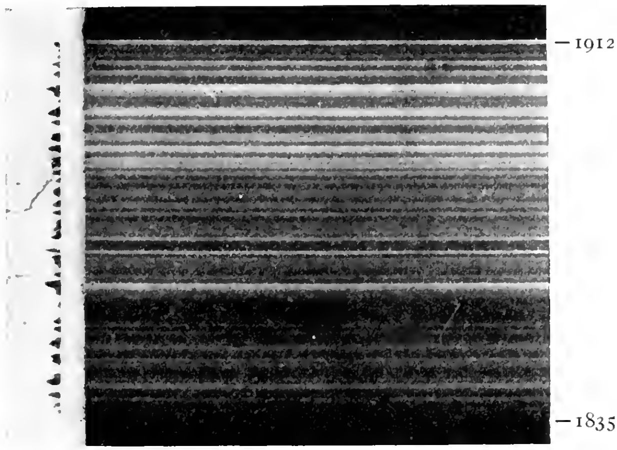


FIG. 4.—Curve of rainfall at Windsor, Vt. (negative), and its "sweep" (positive) from 1835 to 1912.

28 months is believed to be the same as Clayton's result of 25 months, because during the ten years or so preceding 1884 there is a little bend in the fringe which shows that the period was then distinctly less than 28 months, even possibly as low as 25 or 26 months. Arctowski's large allowance of variation easily includes the result here obtained. Hence we find some cause for believing in a period which is not constant. In applying rigid periods this

[1] The curve, shown on a small scale in Fig. 4, was derived as follows: The record of rainfall for every 3 months was smoothed by 4-term overlapping means to get rid of seasonal change. It was then smoothed by Hann's formula (the smoothing here mentioned can be done in the focusing), and "truncated" by a slightly curving line which eliminated coarse variations of ten years or more, leaving the smaller variations. Fig. 5*d* was made directly from this curve. Figs. 5*a*, *b*, and *c* were photographed from a dense photographic negative of the curve.

is likely to be overlooked. The possibility inferred from these photographic results then is that the study of slightly variable periods might open up added fields of knowledge of meteorological phenomena. To the investigation of such periods, the instrument here described is especially adapted.

a b c d

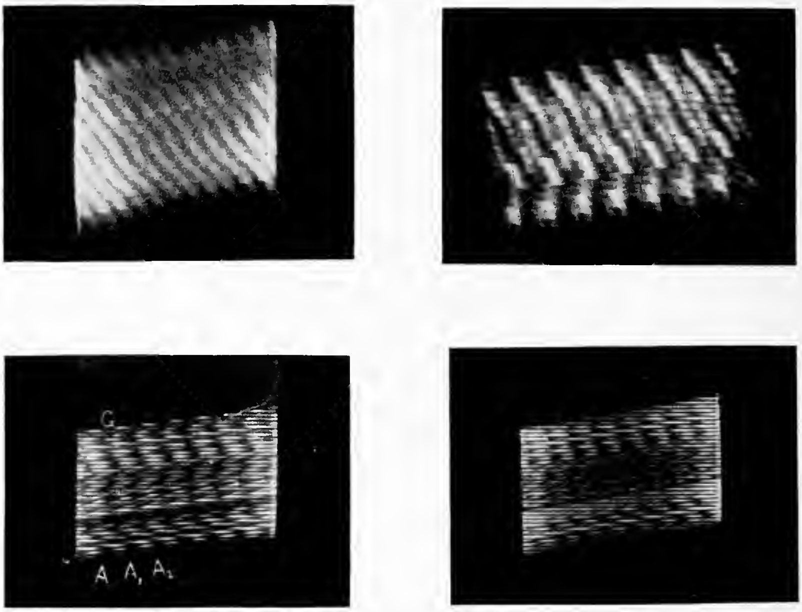


FIG. 5.—Various analyses of rainfall at Windsor, Vt., by the periodograph, showing variation of a suspected 2.3 year period (1912 at top, 1835 at bottom of each). *a*, out of focus, 2.3 year fringes; *b*, out of focus, tested for a 5-year period, it again shows 2.3 year fringes; *c*, in focus, with slight variations of scale and angle from *a*; taken from white curve on black background; *d*, taken from black curve on a white background.

APPLICATION TO THE STUDY OF TREE GROWTH

Fig. 6 shows the application of the periodograph to the analysis of a tree-growth curve. The 500-year record of the yellow pine in northern Arizona, derived from the annual rings, was corrected for decrease of growth with age, reduced to percentages of its own mean, smoothed by Hann's formula, slightly "truncated" to eliminate long fluctuations of over 20 years, and then treated as

described above for the rainfall-curves. The result is shown in the figure. A period varying from 5.1 to 6.3 years seems to be traceable throughout. Taken from end to end it averages 5.7 years. In the later centuries it is evidently a submultiple of an approximate 21-year period. Between 1750 and 1790 a period of 4.3 is shown in this analysis, and from 1860 to 1900 a 7-year period is manifest.

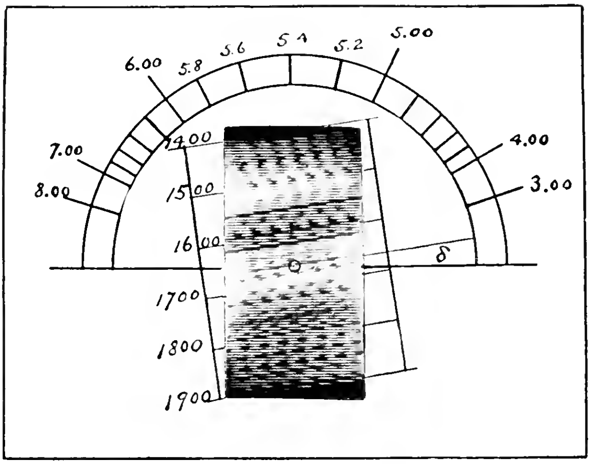


FIG. 6.—Analysis of 500 years of tree-growth record in Arizona to show periods between 3 and 8 years; dates are given on the left; the numbers on the semicircle at the top give the length in years of any period denoted by a fringe extending in that direction.

The vertical fringes suggest a period varying between 5.1 and 6.3 years, best developed between A.D. 1400 and A.D. 1650.

MANIPULATION; ACCURACY

While the optical periodograph has worked satisfactorily in the cases already tested, it has not been free from difficulties. The matter of focus is important. Displacement of the photographic plate a centimeter or two back of the analyzing plane produces a deceptive certainty of result, for the effect of the cylindric lens is to extend the vertical and diminish horizontal alignments. This may be seen in the difference between Figs. 5*a* and 5*c* since the two were taken under nearly the same conditions, but the former is somewhat out of focus. Nevertheless, the actual periods

measured in Figs. 5*a* and 5*b* agree within 2 per cent with those in Figs. 5*c* and 5*d*.

Again, for consistent results the analyzing plate must be close to the focal plane of the sweep. If it is not, then distortion is produced in the micrometer field. In order to bring it in the proper place a microscope with a 1″ or 2″ objective is focused on the analyzing lines while the projection lens is moved back and forth till the sweep-lines are perfectly in focus. After a photograph has been made in the focal plane, then it is proper to take a print of it out of focus, using a large circular source of light, in order to get any desired smoothing effect.

The analysis of a curve and the analysis of its negative should give concordant results. Yet it would not be surprising if in some cases they do not. In the illustration cited Fig. 5*c* is made from a lantern slide showing a transparent white curve against a black background, and Fig. 5*d* is given to show the same results with a curve plotted black on white paper background. The numerical results of measurements on equivalent patterns made with the position micrometer just before the photographing are as follows:

	Period Fig. 5*c*	Period Fig. 5*d*
About 1851 to about 1881	2.39 years	2.34 years
" 1881 " " 1887	2.14 "	2.13 "
" 1887 " " 1902	2.46 "	2.38 "
Mean Period through Entire Series 1835–1912		
A to G	2.303 years	2.274 years
A_1 " G	2.342 "	2.360 "
A_2 " G	2.505 "	2.460 "

These differences, amounting to between 1 and 2 per cent, are doubtless due to different estimates of the direction of fringes.[1]

In changing from a curve expressed in ordinates to one expressed in light-intensities, there is no great drawback for this purpose, although precision is lost. The chief loss is in accuracy of photographic values, for relative intensities will vary slightly with the plate, the exposure, and the time and character of the development.

[1] The ideal condition will perhaps use neither positive nor negative type of curve but a plot, on a neutral tone or gray, of departures from a mean value, positive differences being white, and negative being black.

The illustrations here given and perhaps usually given will tell only a part of the story. It would require a motion picture to tell the whole. The operator at the instrument can see the whole, for it unfolds itself before him as the size of the sweep starting at a minimum increases several hundred per cent. In picking out individual positions for photographs, his own judgment, or personal equation, or prejudice even may enter. But it is a question if they can do material harm, for it seems to the writer almost impossible to estimate offhand what period is being indicated by any fringe on account of the different scales and angles entering every new combination. However, in addition to special photographs, others taken at regular intervals throughout the entire range would give confidence to the reader. A periodogram, though helping very materially, is not completely satisfactory because it may fail to show some promising periods which are not perfectly constant. It is probable that a periodogram of Fig. 5*a* would largely lose the periodic effect there shown.

Again, there may be much uncertainty and perhaps even mistake in judging of the alignments, but the reader to whom the pictures are presented can judge for himself. In fact, the real advantage in this method of analysis is that alternative alignments indicate real uncertainties in the solution, which the reader himself is perfectly able to see and estimate.

In studying diagrams, fringes are emphasized by viewing the print in a slanting direction.

No practical attempt has yet been made to analyze a curve full of sharp variations such as an unsmoothed rainfall curve. A slight variation in focus may be used to smooth such irregularities.

CONCLUSION

In answer to the need of considering secondary variations in any suspected periodic variations, an instrument has been constructed by which, in an hour or two after plotting, the investigator may view all possible periods in a curve and their variations and begin measuring and photographing the promising ones. This optical periodograph is not yet complete, but it is believed that even now it will have some use in preliminary tests of periodic variation

and in some cases save long computations or in others show where rigorous investigation should be applied. Should it prove desirable to enter upon extended studies of slightly varying periods, this instrument gives a rapid method of approaching the work.

University of Arizona
February 5, 1915

LIST OF STARS WITH PROPER MOTION EXCEEDING 0″.50 ANNUALLY[1]

By ADRIAAN VAN MAANEN

Since the publication, by Porter[2] and Kobold,[3] of the lists of stars having proper motions greater than 0″.50 annually, and since the appearance of Bossert's[4] catalogue of proper motions of 2641 stars, there have been published several notes on stars of large proper motion. The following list (Table I), which has been based on all these sources, is, I hope, complete up to 1914.

In the first column is given the current number; in the second and third columns the name and number in the *B.D.* or *C.P.D.* The fourth column contains the magnitude. To have these as homogeneous as possible it seemed best to give the magnitudes of the *B.D.* and *C.P.D.* For the companions of double stars, which are not given in these sources, the difference as given in Burnham's *General Catalogue* is added to the magnitude of the principal stars. For stars not contained in any of these catalogues I have given the magnitudes as given by the authors of the proper motions. These are marked by an asterisk.

In the fifth column is given the spectrum as determined by W. S. Adams (in an unpublished list, for the use of which I feel greatly indebted to Mr. Adams) or by Miss Cannon.[5] The sixth and seventh columns contain α and δ for the equinox of 1900.0; and the eighth and ninth columns the amount and the direction of the proper motion; while the tenth column gives the authority. The last column finally gives some remarks, regarding uncertainties in the proper motions, and, in the case of double stars, the number in Burnham's *General Catalogue.*

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 96.

[2] *Astronomical Journal*, **12**, 25, 1892.

[3] *Der Bau des Fixsternsystems.* Vieweg und Sohn, 1906.

[4] *Catalogue d. mouv. propres de 2641 étoiles*, 1896.

[5] *Harvard Annals*, **50**, 1908.

TABLE I

No.	Name	*B.D.* or *C.P.D.*	Mag.	Spec.	α 1900	δ 1900	μ	ϕ	Authority	Remarks
1	Gi.Z. 16730	−68° 3597	9.0	....	0h 0m 16s	−68° 22′	0″.53	204°.9	Rist.	
2	Lal. 47231[1]	+45 4408	8.3	K5:	0 0 24	+45 16	0.90	98.3	Po.	β 12740
3	Lal. 47231[2]	....	8.3	....	0 0 24	+45 16	0.89	102.9	β	β 12740
4	Lal. 9721	−49 11858	6.2	G	0 1 8	−49 38	0.53	94.8	Boss	
5	β Cass.	+58 3	2.2	F5	0 3 50	+58 36	0.54	110.4	Au.	
6	A. G. Hels. 38	+64 3	7.0	....	0 3 57	+64 31	0.88	86.9	Schulhof	
7	A. G. Chris. 15	+66 7	9.0	....	0 5 22	+66 35	0.91	84.0	Schulhof	
8	Lal. 248	+43 44	8.1	Ma	0 12 40	+43 27	2.82	81.8	Ps.	
9	ζ Toucani	−65 13	5.1	F8	0 14 52	−65 28	2.05	55.9	Po.	
10	A.W. 120	−27 23	8.4	....	0 17 0	−27 16	0.52	74.7	Rist.	
11	Lal. 475	−27 25	8.1	....	0 19 20	−27 35	0.70	86.7	Po.	
12	Lac. 75	−51 48	7.2	....	0 19 48	−51 35	0.57	122.0	Po.	
13	β Hydrae	−77 16	3.3	G	0 20 30	−77 49	2.27	81.9	Po.	
14	Lac. 127	−35 60	7.0	....	0 28 50	−35 32	0.53	180.0	Po.	
15	Pi. 0h130	−25 64	6.5	G5	0 32 13	−25 19	1.41	91.2	Po.	
16	Lal. 999	+ 2 84	7.5	G1	0 34 0	+ 2 35	0.79	68.3	Po.	
17	54 Piscium	+20 85	6.2	K1	0 34 10	+20 43	0.61	231.6	Ps.	
18	Lal. 1045	+39 154	7.0	K3	0 35 20	+39 39	0.81	152.1	Po.	
19	Lal. 1065	−24 60	6.9	K	0 35 31	−24 21	0.79	114.0	Po.	
20	Lac. 172	−60 46	6.1	K	0 35 45	−60 1	1.00	64.5	Po.	
21	Lal. 1198	+ 1 131	8.2	K4	0 39 57	+ 1 15	0.63	180.9	Po.	
22	η Cass.	+57 150	3.8	F8	0 43 3	+57 17	1.19	113.8	Au.	β 426
23	Comp. to η Cass.	....	7.4	....	0 43 3	+57 17	1.19	113.8	Au.	β 426
24	Lal. 1299	+ 4 123	6.0	K1	0 43 8	+ 4 46	1.37	146.9	Au.	
25	Groom. 145	+69 45	7.8	K0	0 43 17	+69 54	0.54	113.4	Greenwich	
26	Lal. 1353	−23 95	7.4	....	0 44 27	−23 46	0.55	76.2	Po.	
27	Lac. 239	−31 92	7.4	....	0 48 6	−30 54	0.71	84.3	M.N.	
28	A. G. Chris. 174	+68 60	9.1	....	0 50 21	+68 31	0.73	111.0	Schulhof	
29	Lal. 1799	+ 4 158	8.3	K6	0 57 12	+ 4 31	0.50	59.6	Po.	
30	A. G. Hels. 914	+63 137	8.7	....	1 0 18	+63 24	1.62	80.1	Bellamy†	

† Miss E. F. Bellamy, *Astronomische Nachrichten*, **195**, 359, 1913.

31	μ Cass.	+54	223	5.7	G3	1^h	$1^m 57$	+54° 26′	3″.73	114°.9	Au.
32	Lal. 1964	+22	176	8.4	K5	1	2 14	+22 26	0.52	167.9	Po.
33	Cp. St. St. 352	−51	162	8.6	....	1	2 21	−51 31	0.50	92.1	Cape
34	Lal. 1966	+60	170	7.8	F3	1	3 18	+61 1	0.69	90.0	Po.
35	Anonymous	....	....	13.0*	....	1	6 1	−72 46	0.73	54.8	Pickering
36	ν Phoenicis	−46	127	6.1	G	1	10 40	−46 4	0.71	76.2	Po.
37	W.B. 1^h161	− 1	167	8.0	G8	1	13 32	− 1 23	0.54	123.7	Po.
38	La. 2387	− 9	256	8.5	....	1	14 1	− 9 27	0.57	208.3	Po.
39	W.B. 1^h262	+30	206	8.8	....	1	15 50	+30 49	0.52	98.0	Rist.
40	Lal. 2450	+17	197	7.9	Go	1	16 52	+18 10	0.57	90.0	Po.
41	W.B. 1^h356	+17	202	8.8	....	1	19 26	+17 59	0.67	106.0	Berlin A
42	Lal. 2682	+20	226	7.8	K1	1	23 35	+21 13	0.53	111.2	Po.
43	Lal. 2975	+28	271	8.5	....	1	32 43	+29 4	0.54	118.6	Po.
44	Lal. 3022	+27	262	7.8	G7	1	33 56	+27 36	0.53	75.7	Po.
45	Lal. 2966	+66	145	7.4	G4	1	34 11	+66 25	0.76	107.7	Po.
46	Lal. 3054	+41	328	5.3	F	1	35 42	+42 7	0.82	100.5	Po.
47	A.Oe. 1867–8	+63	229	8.2	....	1	36 46	+63 20	0.64	206.9	Rist.
48	Lal. 3128	+19	279	5.3	F	1	37 4	+19 47	0.73	204.1	Ps.
49	Lal. 3153	−18	287	7.2	....	1	37 22	−18 24	0.54	93.8	R3
50	τ Ceti	−16	295	3	K	1	39 25	−16 28	1.95	296.1	Ps.
51	Pi. 1^h159	+63	238	6.1	K1	1	40 31	+63 22	0.62	112.8	Po.
52	A.Oe. 1137–8	−23	215	9.0	....	1	48 2	−22 56	0.92	90.0	Po.
53	χ Eridani	−52	241	5.8	G5	1	52 4	−52 6	0.72	65.5	Po.
54	Cp. St. St. 647	−41	183	7.4	....	1	56 18	−41 12	0.58	138.7	Cape
55	Lal. 3922	− 1	293	7.5	Go	2	2 30	− 1 5	0.50	220.9	Po.
56	Lac. 661	−51	282	7.1	G	2	6 24	−51 19	2.28	70.5	Po.
57	Lal. 3987	+67	191	7.8	....	2	7 31	+67 13	0.56	122.6	Ps.
58	W.B. 2^h95	− 1	306	8.3	F5	2	9 28	− 1 40	0.97	95.3	Po.
59	Lal. 4141	+23	303	6.5	G4	2	9 41	+23 49	0.60	106.3	Ps.
60	δ Trianguli	+33	395	5.0	G	2	10 57	+33 46	1.15	101.5	Ps.
61	Lal. 4268	+ 1	410	5.8	F5	2	12 50	+ 1 17	0.49	44.8	Po.
62	A.Oe. 2618	+70	169	8.5	....	2	14 3	+70 43	0.58	69.6	Greenwich
63	A. G. Christ. 416	+68	166	7.5	....	2	14 30	+68 18	0.87	92.3	Schulhof‡

‡ Schulhof marks the P.M. as uncertain, *Bulletin Astronomique*, **27**, 206, 1910.
The Greenwich second *9Y Cat.* gives $\mu = 0''.12$, $p = 60°.9$.

TABLE I—*Continued*

No.	Name	*B.D.* or *C.P.D.*		Mag.	Spec.	α 1900	δ 1900	μ	φ	Authority	Remarks
64	Lal. 4338	−26°	214	7.2	G	2h 14m 30s	−26° 25′	0″.50	330°.9	Po.	
65	A.W. 1327	−17	484	9.4	....	2 26 40	−17 26	0.56	90.0	Po.	
66	Pi. 2h123	+6	398	6.5	K6	2 30 36	+6 25	2.34	51.8	Po.	
67	Lal. 4855	+30	421	7.3	G0	2 32 35	+30 24	0.60	228.4	Po.	
68	A.Oe. 1739.41	−30	324	7.8	....	2 36 17	−30 34	0.66	90.0	Po.	
69	A.Oe. 1753	−30	327	9.0	....	2 37 22	−30 44	0.51	127.4	Po.	
70	A. G. Bonn 2435	+45	669	9.0	....	2 44 54	+45 35	0.64	119.2	Ling	
71	A. G. Berlin A 767	+15	395	9.0	....	2 45 2	+15 19	0.53	141.1	Berlin A	
72	Comp. to Anon. 2h45m54s+22°37′	....		12.1*	....	2 45 44	+22 38	0.87	355.6	β	
73	Anonymous	....		10.4*	....	2 45 54	+22 37	0.71	241.7	Puiseux	
74	W.B. 2h927	+5	435	8.2	G8	2 55 15	+5 36	0.68	102.8	Po.	
75	Lal. 5490	+61	513	6.7	G3	2 55 58	+61 20	1.01	131.4	Po.	
76	ε Fornacis	−28	302	6.6	G	2 57 19	−28 28	0.50	145.7	Po.	
77	ι Persei	+49	857	4.3	G	3 1 51	+49 14	1.25	92.7	Au.	
78	Lal. 5761	+25	495	7.9	A3p	3 2 32	+25 58	0.90	191.6	Po.	
79	Lal. 5986	−29	362	4.2	F	3 7 49	−29 23	0.73	25.2	Au.	
80	W.B. 3h113	+8	482	7.8	K0	3 9 22	+8 37	0.62	131.7	Po.	
81	ζ1 Reticuli	−63	217	6.4	G	3 15 36	−62 57	1.48	65.2	Po.	
82	Lac. 1060	−43	354	5.6	G5	3 15 56	−43 27	3.05	75.5	Po.	
83	ζ2 Reticuli	−62	265	5.6	F8	3 16 2	−62 53	1.44	63.6	Po.	
84	Lal. 6320	−5	642	7.9	K6	3 20 4	−5 42	0.86	198.2	Po.	
85	Lal. 6429	−20	643	8.0	....	3 23 19	−20 10	0.61	61.8	Po.	
86	Lac. 1143	−63	234	5.4	F5	3 27 38	−63 17	0.50	43.4	Po.	
87	ε Eridani	−9	697	3.3	K	3 28 13	−9 48	0.99	270.7	Au.	
88	Lal. 6665	−0	572	4.2	G5	3 31 46	+0 5	0.55	205.6	Ps.	
89	W.B. 3h617	−3	592	7.2	F5	3 35 17	−3 32	0.79	107.7	Po.	
90	δ Eridani	−10	728	3.3	K	3 38 27	−10 6	0.75	350.8	Au.	
91	Cp. St. St. 1228	−51	443	7.2	....	3 40 11	−50 58	0.51	12.3	Cape	
92	Lal. 6888	+41	750	8.2	G6	3 40 12	+41 9	1.38	154.2	Po.	β 1854
93	Comp. to Lal. 6888	....		8.8	....	3 40 12	+41 9	1.38	154.2	Po.	
94	τ6 Eridani	−23	414	4.5	F8	3 42 33	−23 33	0.56	198.8	Po.	

95	A. G. Nicolajew 817	+ 0°	659	8.3	....	3h 44m 24s	+ 1° 3′	0″.68	161°.4	Nicolajew	
96	Lal. 7036	+60	762	7.8	....	3 46 27	+60 53	0.50	117.6	Po.	
97	Cp. St. St. 1272	−42	366	8.4	....	3 47 10	−42 53	0.61	18.1	Cape	
98	Groom. 745	+75	154	8.2	K4	3 48 24	+75 53	0.64	144.6	Po.	
99	Lal. 7443	+34	796	8.5	G5	3 56 32	+35 2	2.19	128.1	Po.	
100	A.W. 2324	−21	784	9.1	....	4 2 12	−21 6	0.71	177.4	Rist.	
101	A. G. Berlin B 1366	+21	607	8.9	....	4 8 36	+22 7	0.51	130.9	Berlin B	
102	o² Eridani	− 7	780	4.7	G5	4 10 40	− 7 49	4.11	212.7	Po.	
103	W.B. 4h166	− 7	781	9.1	A0	4 10 45	− 7 49	4.11	212.7	β	β 2109
104	Comp. to W.B. 4h166	....		10.8	....	4 10 45	− 7 49	4.11	212.7	β	
105	Lal. 8735	+41	931	7.1	G0	4 34 31	+41 56	0.73	127.2	Po.	
106	Cp. St. St. 1594	−50	637	7.6	....	4 43 7	−50 15	0.59	234.4	Cape	
107	Lal. 9012	+45	992	6.5	F8	4 44 22	+45 41	0.68	145.1	Po.	
108	A. G. Leiden 1812	+34	927	8.0	....	4 51 19	+34 7	0.76	114.6	Wilkens	
109	W.B. 4h1189	− 5	1123	6.3	K9	4 55 51	− 5 52	1.25	151.4	Po.	
110	Lal. 9599	+18	779	5.2	G	5 1 32	+18 31	0.53	86.8	Ps.	
111	W.B. 5h87	− 9	1094	8.0	....	5 7 8	− 9 13	0.58	185.0	Rist.	
112	C.Z. 5h243	−44	612	9.2	G–K	5 7 42	−44 59	8.71	131.0	Kapteyn	
113	λ Aurigae	+39	1248	4.9	G1	5 12 6	+40 1	0.84	141.7	Au.	
114	Lal. 9960	− 3	1061	8.5	....	5 14 8	− 3 11	0.73	81.3	Po.	β 2654
115	Comp. to Lal. 9960	....		12.5	....	5 14 8	− 3 11	0.73	81.3	β	
116	Lal. 10299	− 3	1110	8.5	K5	5 23 29	− 3 34	0.89	198.4	Po.	
117	W.B. 5h592	− 3	1123	8.7	....	5 26 23	− 3 42	2.23	161.7	Po.	
118	B.D. −0° 981	− 0	981	9.0	....	5 26 35	+ 0 2	0.52	165.0	Roy	
119	Groom. 990	+51	1094	7.9	K0	5 30 24	+51 23	0.56	279.3	Po.	
120	Pi. 5h146	+53	934	6.3	K0	5 33 14	+53 26	0.55	179.0	Po.	
121	Lal. 10797	+37	1312	7.1	K2	3 39 9	+37 15	0.72	136.1	Po.	
122	π Mensae	−80	161	6.5	G5	5 45 8	−80 33	1.28	10.8	Po.	
123	Cordoba 6886	−70	447	8.6	....	5 45 42	−70 13	1.29	343.1	Rist.	
124	δ Leporis	−20	1211	4.3	K	5 47 1	−20 53	0.69	161.3	Ps.	
125	Lal. 11196	+13	1036	7.0	G2	5 50 21	+13 55	0.69	136.8	Po.	
126	Lac. 2106	−63	498	6.2	K	5 53 20	−63 7	0.50	17.4	Po.	
127	A. G. Berlin A 1866	+19	1185	9.0	....	5 57 12	+19 23	0.76	128.7	Wolf	
128	B.D. +26° 1067	+26	1067	8.9	....	5 59 43	+26 35	0.54	227.1	Wolf	
129	B.D. −21° 1377	−21	1377	8.7	....	6 6 22	−21 49	0.73	186.0	Po.	
130	Comp. to 71 Orionis	....		11.2*	....	6 8 32	+19 11	0.98	194.9	Lau†	

† Lau probably used Burnham's companion C in 1886 and Burnham's companion D in 1909. According to Burnham both companions have no large P.M.

TABLE I—*Continued*

No.	Name	*B.D.* or *C.P.D.*	Mag.	Spec.	α 1900	δ 1900	μ	φ	Authority	Remarks
131	Cp. St. St. 2181	−42° 915	7.4	......	$6^h21^m21^s$	−42° 49′	0″.75	346°.6	Cape	
132	Groom. 1159	+79 212	5.5	A2	6 29 10	+79 40	0.66	186.1	Po.	
133	Gi.Z. 4158	−68 536	8.9	......	6 32 29	−68 37	0.50	195.0	Rist.	
134	α Canis Majoris	−16 1591	1.0	A	6 40 45	−16 35	1.31	203.8	Au.	} β 3596
135	Comp. to α Canis Maj	......	9.0†	......	6 40 45	−16 35	1.31	203.8	Au.	
136	Lal. 13284	− 5 1844	6.9	K9	6 47 26	− 5 3	0.57	270.0	Po.	
137	A. G. Bonn 5621	+40 1758	8.3	......	6 49 30	+40 13	0.57	155.7	Bn.	
138	Lac. 2501	−28 1525	7.2	F	6 49 35	−28 24	0.58	145.5	Po.	
139	W.B. 6^h1500	+ 1 1600	8.0	G3	6 51 24	+ 1 18	0.57	169.9	Po.	
140	Lal. 13427	+48 1469	8.2	K1	6 54 0	+48 32	0.71	124.1	Po.	
141	Lal. 13576	+29 1441	6.3	F9	6 57 9	+29 30	0.82	168.0	Po.	
142	Lal. 13849	+21 1528	7.0	G6	7 4 11	+21 25	0.52	196.7	Po.	
143	Cp. St. St. 2483	−49 1163	7.6	......	7 8 53	−49 17	0.77	359.3	Cape	
144	Lal. 14146	−12 1871	7.3	F9	7 11 16	−12 53	0.55	283.8	Po.	
145	Lac. 2740	−46 1360	7.5	......	7 14 37	−46 49	0.60	342.5	Po.	
146	α Canis Minoris	+ 5 1739	1.0	F5	7 34 4	+ 5 29	1.25	215.0	Au.	} β 4187
147	Comp. to α Canis Min	......	13.0†	......	7 34 4	+ 5 29	1.25	215.0	Au.	
148	W.B. 7^h1029	+39 1998	6.8	......	7 38 9	+39 49	0.52	174.8	Rist.	
149	β Geminorum	+28 1463	1.3	K	7 39 12	+28 16	0.63	265.5	Au.	
150	Groom. 1339	+80 238	6.5	G6	7 39 45	+80 31	0.50	272.3	Po.	
151	T Puppis	−44 1829	6.6	F8	7 39 52	−44 55	0.55	183.1	Po.	
152	Lac. 2957	−33 1748	7.1	......	7 41 51	−33 59	1.68	351.1	Po.	
153	Lal. 15290	+31 1684	8.2	F7	7 47 10	+30 55	1.97	158.3	Po.	
154	Lal. 15394	+19 1869	8.2	......	7 49 5	+19 31	0.50	170.4	β	
155	Lal. 15547	+21 1731	8.5	......	7 53 41	+21 8	0.59	159.1	Po.	
156	A.Oe. 7734	−25 3148	9.0	......	7 53 50	−25 21	0.52	122.5	Po.	
157	Lal. 15565	+29 1664	7.5	G7	7 54 21	+29 31	1.19	186.8	Po.	
158	Lac. 3122	−59 944	6.6	F2	7 55 56	−60 2	0.56	77.7	Po.	
159	Fed. 1221	+72 395	8.0	......	7 57 13	+72 13	0.50	333.7	Greenwich	
160	Lac. 3152	−29 2316	7.8	......	8 2 55	−29 6	0.56	141.0	St.	
161	Lal. 15950	+32 1695	6.7	G2	8 5 23	+32 46	0.82	213.5	Po.	

† Magnitude uncertain.

162	Fed. 1266	+73°	407	8.5	....	8h 8m 47s	+73° 44′	0″.58	330°.7	Greenwich	
163	W.B. 8h224	−11	2296	9.3	....	8 11 32	−11 27	0.72	59.0	Rist.	
164	W.B. 8h181	+31	1781	8.3	K5	8 12 0	+30 56	0.90	200.3	Po.	
165	Lal. 16304	−12	2449	6.3	G9	8 13 39	−12 18	1.03	166.5	Po.	
166	A.Oe. 8869	+66	550	8.8	....	8 16 21	+66 48	0.52	1.0	Greenwich	
167	A. G. Cambridge 3181	+54	1244	8.6	....	8 28 12	+54 4	0.93	92.6	Cambridge	
168	W.B. 8h596	+42	1899	8.5	....	8 28 48	+42 6	0.76	202.1	Rist.	
169	Lac. 3386	−31	2448	7.6	G2	8 28 57	−31 11	1.32	301.4	Po.	
170	Lal. 17046	+12	1888	8.1	....	8 34 23	+11 53	0.52	194.6	Po.	
171	Lal. 17161	+42	1922	8.2	Kc	8 38 35	+42 3	0.69	204.0	Po.	
172	Fed. 1384[1]	+71	482	8.5	Ma	8 45 59	+71 11	1.40	255.6	Po.	β 4815
173	Fed. 1384[2]	......	......	8.6	....	8 45 59	+71 11	1.38	256.9	β	β 4815
174	ρ^1 Cancri	+28	1660	6.0	Ko	8 46 39	+28 43	0.55	243.9	Po.	
175	ι Ursae Majoris	+48	1707	3.1	A5	8 52 22	+48 26	0.51	240.4	Au.	β 4866
176	Comp. B. to ι Ursae Maj.	......	......	9.5	....	8 52 22	+48 26	0.51	240.4	β	β 4866
177	Comp. C. to ι Ursae Maj.	......	......	9.8	....	8 52 22	+48 26	0.51	240.4	β	β 4866
178	Lal. 17697	+42	1956	4.1	F5	8 54 9	+42 11	0.52	240.0	Ps.	
179	C. du C. +26° 25798	......	......	11.2	....	8 59 53	+25 42	0.50	229.8	Turner	
180	Lal. 18067	−14	2757	7.2	....	9 3 46	−14 44	0.54	244.8	Po.	
181	Lal. 18137	+15	2003	7.0	G	9 6 49	+15 24	0.60	294.5	Po.	
182	Lal. 18115[1]	+53	1320	8.0	K8	9 7 35	+53 7	1.69	248.5	Po.	β 4972
183	Lal. 18115[2]	+53	1321	8.0	K8	9 7 36	+53 7	1.69	248.5	Po.	β 4972
184	Lal. 18286	+29	1883	7.0	K3	9 11 57	+29 0	0.52	173.4	Po.	
185	Lal. 18397	+40	2197	7.5	K7p	9 16 8	+40 38	0.55	223.5	Po.	Sp. Bin.
186	Lal. 18672	+ 6	2182	7.7	....	9 24 43	+ 6 5	0.54	282.3	Po.	
187	θ Ursae Majoris	+52	1401	3.0	F8	9 26 10	+52 8	1.11	239.7	Au.	Sp. Bin. β 5123
188	Comp. to θ Ursae Maj	......	......	13.7	....	9 26 10	+52 8	1.11	239.7	β	β 5123
189	Lal. 18812	+36	1979	5.5	G7	9 29 40	+36 16	0.77	249.4	Po.	
190	Lal. 19022	+43	1953	8.0	K5	9 37 7	+43 10	0.80	180.0	Po.	
191	Lal. 19229	+14	2151	8.2	A3p	9 43 28	+14 14	0.83	156.6	Po.	
192	W.B. 9h954	−11	2741	9.3	....	9 46 10	−11 49	1.95	140.2	Po.	
193	Groom. 1596	+56	1421	8.2	G6	9 54 53	+56 5	0.49	205.0	Po.	
194	Lal. 19545	+32	1964	5.8	G1	9 55 15	+32 25	0.69	230.3	Ps.	
195	Groom. 1618	+50	1725	6.8	K7	10 5 15	+49 58	1.45	248.9	Po.	
196	A. G. Cambridge 3591	+51	1585	6.5	....	10 7 21	+50 59	0.89	271.2	Cambridge	

TABLE I—*Continued*

No.	Name	*B.D.* or *C.P.D.*	Mag.	Spec.	α 1900	δ 1900	μ	φ	Authority	Remarks
197	A.Oe. 10640	+53° 1395	9.2	......	10h 7m 28s	+53° 1′	0″.70	174°.3	Rist.	
198	W.B. 10h234	+20 2465	9.2	......	10 14 11	+20 22	0.51	270.0	Po.	
199	Munich II 5178	− 0 2326	8.8	......	10 15 42	− 0 58	0.70	255.1	Nicolajew	
200	Groom. 1646	+49 1961	6.2	F9	10 21 54	+49 19	0.90	173.0	Po.	
201	W.B. 10h366	− 5 3071	8.0	......	10 23 13	− 6 5	0.50	232.2	Po.	
202	W.B. 10h520	−11 2918	5.7	F1	10 31 34	−11 42	0.74	156.9	Po.	
203	Lal. 20881	+21 2247	7.9	......	10 46 7	+20 49	0.50	210.2	Po.	
204	Lal. 21008	+28 1952	8.3	......	10 50 52	+28 17	0.50	254.8	Po.	
205	A. G. Berlin C 1500	+70 639	9.5	......	10 50 59	+70 8	0.66	270.0	Berlin C.	
206	Lal. 21120	−17 3273	4.0	K	10 54 54	−17 46	0.50	286.3	Ps.	
207	Lal. 21185	+36 2147	7.3	Ma	10 57 53	+36 38	4.77	186.4	Po.	
208	Lal. 21258	+44 2051	8.5	Ma	11 0 31	+44 2	4.47	282.8	Po.	
209	Lac. 4606	−29 3437	7.6	G	11 3 9	−29 38	0.51	252.1	Po.	
210	Comp. to Lal. 21368	....	9.5	......	11 5 32	+31 0	0.58	110.3	Po.	β 5695
211	Lal. 21368	+31 2240	8.5	......	11 5 35	+31 0	0.58	110.3	Po.	
212	Anonymous	....	9.5*	......	11 5 54	+ 6 59	0.97	226.4	Wolf	
213	A. G. Washington 4420	−14 3277	9.0	......	11 6 28	−14 26	0.90	130.7	Washington	
214	A. G. Nicolajew 3220	− 1 2505	9.4	......	11 12 11	− 1 26	0.62	268.3	Nicolajew	
215	Lal. 21554	+32 2132	3.7	G	11 12 51	+32 6	0.74	219.5	Au.	Sp. Bin.
216	Comp. to Lal. 21554	....	4.6	G	11 12 51	+32 6	0.74	219.5	Au.	β 5734
217	Lal. 21565	− 4 3049	7.2	G6	11 13 12	− 4 31	0.79	100.9	Po.	
218	A.Oe. 11677	+66 717	9.0	......	11 14 50	+66 23	3.03	274.5	Po.	
219	83[1] Leonis	+ 3 2502	7.5	G8	11 21 42	+ 3 33	0.75	283.1	Po.	β 5779
220	83[2] Leonis	+ 3 2503	8.0	K8	11 21 43	+ 3 33	0.68	283.8	Ps.	
221	Anonymous	....	9.7	......	11 23 20	+ 8 6	1.23	190.4	β	
222	Br. 1584	−32 3122	6.7	G	11 29 38	−32 18	1.08	321.0	Po.	
223	Lal. 22069[2]	....	8.6	......	11 33 28	+45 40	0.63	272.7	Po.	β 5858
224	Lal. 22069[1]	+45 1947	6.5	F9	11 33 29	+45 40	0.63	272.7	Po.	
225	Cp. St. St. 4223	−43 5524	8.3	......	11 36 14	−43 51	0.72	284.8	Cape	
226	A. G. Chris. 1806	+68 658	8.8	......	11 36 48	+68 44	0.67	270.0	Schulhof†	

† Schulhof marks the P.M. as uncertain, *loc. cit.*

227	Groom. 1822	+48°	1964	7.8	G0	11h40m18s	+48°14′	0″.66	245°.0	Po.	
228	Lac. 4887	−39	5265	5.8	G	11 41 45	−39 57	1.58	284.3	Po.	
229	β Leonis	+15	2383	2.0	A2	11 43 58	+15 8	0.53	259.1	Au.	
230	β Virginis	+ 2	2489	3.3	F8	11 45 29	+ 2 20	0.77	109.9	Au.	
231	Groom. 1830	+38	2285	6.5	G5	11 47 13	+38 26	7.06	145.3	Po.	
232	W.B. 11h920	+20	2658	8.2	....	11 49 27	+19 58	0.50	272.3	Berlin B	β 5960
233	W.B. 11h921	+20	2659	8.2	....	11 49 30	+19 59	0.50	272.3	β	
234	Lac. 4955	−26	4626	7.5	....	11 52 59	−27 8	1.21	234.8	Po.	
235	Lal. 22585	− 9	3413	6.4	G6	11 55 36	− 9 53	0.50	175.4	Po.	
236	Lal. 22632	+43	2182	6.7	G6	11 57 25	+43 39	0.67	213.5	Po.	
237	Lal. 22667	+ 4	2568	9.0	....	11 58 58	+ 3 55	0.55	173.8	Po.	
238	Lal. 22701	− 0	2532	8.4	....	12 0 9	− 0 57	0.51	270.0	Po.	
239	W.B. 12h69	− 2	3481	7.3	G4	12 7 25	− 2 32	0.73	304.4	Po.	
240	Lal. 22901	+10	2391	8.1	....	12 7 50	+10 36	0.52	35.0	Ps.	
241	Lal. 22908	+11	2439	8.0	G3	12 8 7	+11 24	0.59	177.1	Po.	
242	Lal. 22954	− 9	3468	6.2	F6	12 10 2	− 9 44	1.03	176.1	Po.	
243	B.D. +29° 2279	+29	2279	9.5	....	12 14 28	+28 56	0.66	291.7	Wolf	
244	W.B. 12h309	+42	2296	8.8	....	12 16 56	+42 42	0.65	149.8	Rist.	
245	Anonymous	......	......	10.7	....	12 17 25	+25 44	0.79	293.0	Wolf	
246	Lac. 5123	−66	1752	7.6	K	12 17 51	−67 5	0.82	281.3	Po.	
247	A.Oe. 12584	+74	493	8.0	....	12 17 54	+73 48	0.50	248.4	Greenwich	
248	A. G. Lund 5422	+39	2519	7.5	....	12 19 55	+38 52	0.61	272.9	Lund	
249	Lal. 23243	+32	2244	8.9	....	12 20 22	+32 25	0.50	239.2	Po.	
250	Cp. St. St. 4496	−48	4709	7.6	G	12 21 31	−48 21	0.63	261.7	Cape	
251	Lal. 23361	− 2	3528	8.5	....	12 24 37	− 2 46	0.69	205.8	Po.	
252	Lal. 23498	+42	2321	4.5	G	12 29 0	+41 54	0.78	291.8	Ps.	
253	Gi.Z. 8755	−77	859	9.3	....	12 33 33	−77 18	0.83	294.0	Rist.	
254	γ Virginis[1]	− 0	2601	2.8	F	12 36 36	− 0 54	0.57	272.0	Ps.	β 6243
255	γ Virginis[2]	......	......	2.8	F	12 36 36	− 0 54	0.57	272.0	Ps.	
256	C.P.D. −37° 5339	−37	5339	7.9	....	12 38 24	−37 9	0.69	250.9	Kapteyn	
257	Lal. 23808	+10	2468	6.4	K1	12 41 18	+10 6	0.52	149.0	Ps.	
258	Lal. 23917	+ 2	2585	8.2	....	12 44 39	+ 1 45	0.68	182.5	Po.	
259	Lal. 23995	−17	3723	8.2	....	12 47 56	−17 57	0.89	159.5	Po.	
260	δ Virginis	+ 4	2669	3.0	Ma	12 50 34	+ 3 56	0.50	264.3	Po.	
261	Lal. 24168	− 9	3595	7.7	G9	12 53 54	− 9 18	0.82	282.0	Po.	

TABLE I—*Continued*

No.	Name	*B.D.* or *C.P.D.*	Mag.	Spec.	α 1900	δ 1900	μ	φ	Authority	Remarks
262	A. G. Nicolajew 3508	− 1° 2754	9.1	......	$12^h55^m14^s$	− 2° 10′	0″.90	270°.6	Nicolajew	
263	A.Oe. 12585	−26 4871	7.9	......	12 56 5	−26 50	0.54	240.1	Po.	
264	W.B. 12^h920	− 7 3525	8.5	......	12 56 10	− 7 54	0.54	256.0	Po.	
265	Cp. St. St. 4746	−40 6050	9.2	......	13 2 58	−41 6	0.69	268.1	Cape	
266	Lal. 24414	+ 6 2697	6.8	G3	13 3 47	+ 5 46	0.72	175.2	Po.	
267	A. G. Washington 5002	−15 3605	9.1	......	13 3 50	−16 13	0.50	180.0	Washington	Only μ δ
268	Lal. 24504	+10 2519	8.5	......	13 6 25	+10 9	0.54	297.5	Po.	
269	A.Oe. 13407	+68 714	8.5	......	13 7 2	+68 2	0.74	272.0	Greenwich	
270	Lal. 24522	+28 2193	5.0	G	13 7 12	+28 23	1.20	318.7	Po.	
271	A. G. Berlin A 4855	+18 2700	7.8	......	13 7 31	+18 3	0.60	273.4	Berlin A	
272	Lal. 24652	+17 2611	7.0	......	13 11 52	+17 35	0.70	113.6	Krüger	β 6442
273	Comp. to Lal. 24652	....	10.1	......	13 11 52	+17 35	0.70	113.6	Krüger	
274	Lal. 24680	−17 3813	5.0	K	13 13 10	−17 45	1.51	225.5	Po.	
275	W.B. 13^h241	+35 2436	9.0	......	13 14 55	+35 39	0.92	154.3	Po.	β 6452
276	Comp. to W.B. 13^h241	....	11.5	......	13 14 56	+35 39	0.92	154.3	β	
277	W.B. 13^h216	+ 4 2729	8.5	......	13 15 43	+ 4 39	0.58	292.2	Po.	
278	Anonymous	....	11.0*	......	13 18 31	−13 31	0.61	232.8	Wolf	
279	Lal. 24838	+29 2405	8.6	......	13 18 55	+29 45	0.54	299.1	Po.	
280	Lal. 24915	− 0 2691	8.0	......	13 23 9	− 0 19	0.50	149.3	Nicolajew	
281	Lal. 24926	+14 2621	5.5	F	13 23 32	+14 19	0.64	204.2	Po.	
282	B.D. −7° 3632	− 7 3632	9.5	......	13 25 7	− 8 3	1.20	250.7	Wolf	
283	Lal. 25012	− 1 2832	7.5	G6	13 26 36	− 1 49	0.91	284.7	Po.	
284	ι Centauri	−32 3479	4.9	F5	13 40 0	−32 32	0.51	251.6	Po.	
285	A. G. Berlin A 4999	+18 2776	9.2	......	13 40 13	+18 21	1.92	169.6	Berlin A	
286	Lal. 25372	+15 2620	8.5	Ma5	13 40 40	+15 26	2.32	129.2	Po.	
287	Lal. 25404	+ 7 2690	6.5	F5	13 42 0	+ 6 51	0.50	254.8	Po.	
288	Lal. 25426	+18 2782	4.6	F5	13 42 31	+17 57	0.50	274.7	Po.	
289	Lal. 25484	−23 5802	6.8	F8	13 45 50	−23 53	0.68	238.9	Po.	
290	Cp. St. St. 5010	−50 6387	7.8	......	13 46 20	−50 26	0.65	266.8	Cape	
291	C. du C. +25° 86067	....	10.4*	......	13 54 49	+25 44	0.54	262.4	Bellamy	
292	θ Centauri	−35 6109	3.4	K	14 0 48	−35 53	0.78	225.0	Po.	

293	α Boötis	+19° 2777	1.0	K	$14^h 11^m 6^s$	+19° 42′	2″.28	209°.6	Au.	
294	C.P.D. −58° 5467	−58 5467	8.0	....	14 12 0	−58 54	0.93	214.5	Kapteyn	
295	Lal. 26196	− 4 3665	7.6	K1	14 14 25	− 4 41	0.65	259.4	Po.	
296	Lal. 26294	+30 2512	8.3	....	14 17 40	+30 6	0.56	296.3	Ps.	
297	Lal. 26289	+ 1 2920	6.5	G0	14 18 8	+ 1 43	0.55	156.3	Po.	
298	A. G. Berlin B 5072	+24 2733	9.0	....	14 21 5	+24 6	1.38	143.5	Po.	β 6869
299	A. G. Berlin B 5073	....	9.0	....	14 21 9	+24 6	1.38	143.5	Po.	
300	C. du C. +25° 42937	+24 2735	9.5	....	14 23 17	+24 17	0.50	273.1	Bellamy	
301	B.D. −7° 3856	− 7 3856	9.0	....	14 25 38	− 8 12	1.23	260.0	Hayden	
302	B.D. +10° 2703	+10 2703	8.4	....	14 28 40	+ 9 47	0.53	162.1	Po.	
303	A. G. Leiden 5231	+34 2541	9.0	....	14 30 54	+34 10	0.74	342.7	Kapteyn	
304	Lal. 26630	−11 3770	6.0	F5	14 31 40	−11 53	0.96	292.0	Po.	
305	α² Centauri	−60 5483	2.1	G	14 32 48	−60 25	3.68	281.9	Po.	
306	α¹ Centauri	....	3.0*	K5	14 32 49	−60 25	3.68	281.9	St.	
307	W.B. 14^h847	+17 2785	8.8	....	14 41 43	+16 56	0.94	185.4	Kobold	
308	W.B. 14^h810	+ 7 2850	9.1	....	14 45 29	+ 7 14	0.62	203.6	Po.	
309	Lal. 27026	−23 5999	8.0	....	14 46 0	−23 53	1.02	241.9	Po.	
310	Lal. 27137	+19 2881	6.3	K	14 48 51	+19 33	0.53	242.4	Ps.	
311	Lal. 27155	+23 2751	8.5	....	14 49 20	+23 45	0.75	275.0	Ps.	
312	Yarnall 6246	−20 4123	8.7	....	14 51 36	−20 58	2.01	151.4	Gr.	β 7060
313	Lal. 27173	−20 4125	6.0	K6	14 51 37	−20 58	2.06	150.7	Po.	
314	Lal. 27298	+54 1716	7.7	K0	14 52 21	+54 4	1.08	296.3	Po.	
315	Lal. 27274	−21 4009	8.3	....	14 54 9	−21 36	0.80	227.6	Po.	
316	W.B. 14^h989	−10 4011	9.3	....	14 55 18	−10 44	0.54	180.0	Po.	
317	Cp. St. St. 5447	−48 7086	8.7	....	14 59 14	−48 53	0.55	186.7	Cape	
318	Lal. 27531	− 7 3963	8.0	....	15 2 53	− 7 31	0.50	198.8	Po.	
319	Lal. 27558	+ 9 3001	8.7	....	15 2 58	+ 9 16	0.54	258.2	Ps.	
320	B.D. +25° 2874	+25 2874	9.2	....	15 3 8	+25 18	0.92	298.5	Po.	
321	A.Oe. 14318	−15 4041	9.2	....	15 4 44	−15 59	3.76	194.8	Po.	
322	A.Oe. 14320	−15 4042	9.0	G0	15 4 45	−15 54	3.75	194.7	Po.	
323	Lal. 27742	+19 2939	6.7	G4	15 8 15	+19 39	0.68	296.2	Po.	β 7162
324	Lal. 27743	....	7.6	G6	15 8 15	+19 40	0.62	295.3	Ps.	
325	Lal. 27744	− 0 2944	7.0	G7	15 8 50	− 0 58	1.38	247.4	Po.	
326	Lal. 27917	+ 2 2944	5.0	G	15 14 12	+ 2 9	0.65	146.3	Ps.	β 7213
327	Comp. to Lal. 27917	....	10.0	....	15 14 12	+ 2 9	0.65	146.3	β	

TABLE I—*Continued*

No.	Name	*B.D.* or *C.P.D.*	Mag.	Spec.	α 1900	δ 1900	μ	φ	Authority	Remarks
328	Lal. 27058	+26° 2677	8.0	G2	$15^h 14^m 45^s$	+26° 4′	0″.51	257°.6	Po.	
329	Cp. St. St. 5545	−47 7075	7.2	G	15 15 4	−47 57	1.67	260.8	Cape	
330	Comp. to A. G. Leiden 5456	......	9.4	......	15 16 5	+31 3	1.04	113.6	Wilkens	β 7226
331	A. G. Leiden 5456	+31 2722	9.2	......	15 16 6	+31 3	1.04	113.6	Wilkens	
332	W.B. 15^h268	+ 1 3071	8.7	......	15 17 40	+ 1 47	0.52	230.5	Po.	
333	W.B. 15^h716	+40 2903	7.8	K6	15 32 23	+40 10	0.50	278.1	β	
334	W.B. 15^h720	+40 2905	6.8	K1	15 32 29	+40 8	0.50	278.1	Po.	β 7332
335	Comp. to W.B. 15^h720	......	7.1	......	15 32 29	+40 8	0.50	278.1	Po.	
336	Lal. 28607	−10 4149	7.0	A2p	15 37 42	−10 36	1.18	253.3	Po.	
337	Lac. 6521	−37 6571	6.9	G	15 40 59	−37 36	0.59	240.4	Po.	
338	Lal. 28935	+13 3024	6.3	G	15 48 33	+13 31	0.61	197.2	Po.	
339	Lal. 28992	+42 2648	4.3	F	15 49 13	+42 44	0.75	35.2	Po.	
340	Cp. St. St. 5767	−47 7499	9.0	......	15 50 15	−47 21	0.86	262.9	Cape	
341	γ Serpentis	+16 2849	3.8	F8	15 51 50	+15 59	1.32	168.2	Au.	
342	W.B. 15^h1323	+28 2503	8.0	......	15 54 32	+28 1	0.85	291.5	Bur. des Long. 1913	
343	Lal. 29085	−16 4196	6.2	F	15 54 43	−16 14	0.77	239.4	Po.	
344	Lal. 29213	+33 2663	5.7	F	15 57 13	+33 36	0.81	194.2	Po.	
345	Lal. 29307	+25 3020	7.5	......	15 59 56	+25 31	0.87	211.1	Ps.	
346	Lal. 29330	+11 2910	8.5	......	16 1 12	+10 57	0.50	256.2	Po.	
347	Lal. 29381	+39 2947	6.5	G5	16 1 30	+39 26	0.55	275.2	Po.	
348	Lal. 29439	+39 2950	8.4	......	16 2 54	+38 55	0.60	159.4	Po.	
349	Lal. 29437	+ 6 3169	6.5	K1	16 4 16	+ 6 40	0.79	162.3	Po.	
350	Lal. 29617	− 7 4242	5.9	G1	16 10 11	− 8 6	0.55	157.7	Po.	
351	Lal. 29917	+67 935	8.6	......	16 16 32	+67 29	0.50	281.9	Po.	
352	Comp. to Lal. 29917	......	10.6	......	16 16 34	+67 30	0.50	281.9	β	
353	Anonymous	......	10.7*	......	16 21 7	+48 36	1.24	111.4	Kapteyn	
354	W.B. 16^h400	+ 3 3203	8.9	......	16 23 36	+ 3 29	0.51	180.0	Po.	
355	Lal. 30024^1	+18 3182	7.0	K1	16 24 29	+18 37	0.53	319.7	Po.	β 7642
356	Lal. 30024^2	......	7.0	......	16 24 29	+18 37	0.53	319.7	β	
357	Cp. St. St. 5969	−40 7356	9.5	......	16 25 32	−40 6	1.06	317.1	Cape	

358	Lal. 30044	+ 4°	3195	7.6	F6	16h 25m 33s	+ 4° 26′	1″.46	197°.9	Po.	
359	Lal. 30191	− 1	3220	5.8	F	16 31 6	− 2 7	0.55	126.1	Boss	
360	Lal. 30271	+31	2873	7.2	F2	16 32 34	+31 9	0.49	177.2	Po.	
361	W.B. 16h964	+31	2875	9.1	......	16 32 55	+31 19	0.60	141.0	Rist.	
362	Lal. 30433	+31	2884	3.0	G	16 37 31	+31 47	0.62	311.7	Au.	Sp. Bin.
363	Comp. to Lal. 30433	......		6.5	......	16 37 31	+31 47	0.62	311.7	Au.	β 7717
364	A. G. Chris. 2517	+66	969	9.0	......	16 38 44	+66 7	0.64	269.7	Schulhof†	
365	Lal. 30699	+68	883	7.6	G7	16 42 51	+68 16	0.52	235.3	Greenwich	
366	ε Scorpii	−34	6635	5.0	K	16 43 41	−34 7	0.68	245.7	Po.	
367	Lal. 30694	+ 0	3593	7.0	G6	16 47 56	+ 0 11	1.66	206.1	Po.	
368	W.B. 16h906	− 8	4352	8.8	Mb	16 50 8	− 8 9	1.27	226.8	Po.	
369	C. du C. +25° 48511	+25	3173	9.4	......	16 54 4	+25 55	0.52	188.0	Bellamy	
370	Lal. 31132	+47	2420	6.6	G5	16 59 47	+47 12	0.83	9.0	Po.	
371	Lal. 31055	− 4	4225	7.5	K5	16 59 51	− 4 54	1.48	218.9	Po.	
372	C.P.D. −75° 1368	−75	1368	8.0	......	17 9 0	−75 14	1.03	265.3	Kapteyn	
373	Lal. 31311[1]	−26	5858	5.5	K	17 9 12	−26 27	1.29	203.8	Po.	β 7905
374	Lal. 31311[2]	......		5.5	K	17 9 12	−26 27	1.29	203.8	β	
375	B.D. +42° 2810	+42	2810	9.4	......	17 10 0	+42 28	1.11	250.5	Kostinsky	
376	Br. 2179	−26	5863	8.0	K3	17 10 4	−26 24	1.25	204.1	Po.	
377	Cp. St. St. 6241	−46	8513	7.3	K	17 11 28	−46 32	0.95	72.1	Cape	
378	Lac. 7215	−34	6803	7.2	K5	17 12 9	−34 53	1.20	100.1	Po.	
379	Lal. 31618	+32	2896	5.7	Go	17 16 55	+32 36	1.06	172.9	Po.	
380	Cp. St. St. 6277	−41	7979	8.2	......	17 17 47	−41 24	0.58	82.9	Cape	
381	W.B. 17h322	+ 2	3312	8.0	K9	17 20 47	+ 2 14	1.36	206.2	Po.	
382	A. G. Leiden 6197	+31	3025	9.1	......	17 22 57	+31 8	0.52	285.6	Wilkens	
383	Lal. 32047	+67	1014	6.5	K1	17 25 19	+67 23	0.52	273.3	Po.	
384	A. G. Chris. 2661	+68	930	8.8	......	17 26 14	+68 27	0.80	88.0	Schulhof†	
385	W.B. 17h514	+ 6	3455	8.5	F1	17 29 53	+ 6 4	0.58	308.7	Po.	
386	Anonymous	......		9.1*	......	17 33 27	+18 37	1.29	40.0	Slocum	
387	Lal. 32324	+61	1678	6.0	F	17 33 57	+61 57	0.56	153.4	Po.	β 8090
388	Comp. to Lal. 32324	......		10.6	......	17 33 57	+61 57	0.56	153.4	β	
389	B.D. +18° 3424	+18	3424	9.2	......	17 34 20	+18 37	1.20	311.6	Berlin A‡	
390	A. G. Chris. 2703	+68	941	8.3	......	17 35 47	+68 52	0.83	279.2	Schulhof	

† Schulhof marks the P.M. as uncertain, *loc. cit.*

‡ Berlin A has a small weight for the P.M. of this star. Slocum gives $\mu = 0''.09$, $p = 144°.7$, *Astrophysical Journal*, **38**, 15, 1913

TABLE I—*Continued*

No.	Name	*B.D.* or *C.P.D.*	Mag.	Spec.	α 1900	δ 1900	μ	φ	Authority	Remarks
391	Lal. 32322	+37° 2926	8.4	......	$17^h 36^m 15^s$	+37° 16′	0″.88	204°.2	Ps.	
392	A.Oe. 17415	+68 946	9.1	Mb	17 37 0	+68 26	1.30	196.5	Po.	
393	Lal. 32390	+21 3198	7.5	......	17 39 2	+21 40	0.61	175.3	Ps.	
394	Comp. B. to Lal. 32519	....	10.5	......	17 42 31	+27 47	0.81	203.4	β	
395	Comp. C. to Lal. 32519	....	11.0	Ma	17 42 31	+27 47	0.81	203.4	β	β 8162
396	Lal. 32519	+27 2888	3.5	G5	17 42 33	+27 47	0.81	203.4	Po.	
397	B.D. +26° 3151	+26 3151	7.3	......	17 58 26	+26 20	0.66	148.0	Po.	
398	Lal. 33169	+ 2 3482	4.0	K	18 0 24	+ 2 31	1.15	167.4	Po.	Sp. Bin.
399	Comp. to Lal. 33169	....	6.0	......	18 0 24	+ 2 31	1.15	167.4	Po.	β 8340
400	A. G. Washington 6520	−16 4706	9.1	......	18 0 31	−16 42	0.55	90.0	Washington	Only μ α
401	Lal. 33439	+38 3095	6.7	K2	18 6 19	+38 27	0.62	217.5	Rist.	
402	Lal. 33802	− 2 4599	3	K	18 16 8	− 2 55	0.91	221.4	Au.	
403	B.D. +8° 3689	+ 8 3689	8.0	G1	18 21 25	+ 8 44	0.49	200.4	Kapteyn	
404	B.D. +8° 3692	+ 8 3692	8.5	G5	18 21 37	+ 8 34	0.50	202.7	Kapteyn	
405	Lal. 34392	+72 839	3.8	F8	18 22 52	+72 41	0.63	125.9	Au.	
406	A. G. Leiden 6797	+31 3330	8.7	......	18 37 7	+31 28	0.82	174.8	Wilkens	
407	Pos. Med. 2164[1]	+59 1915	8.9	Mb	18 41 40	+59 29	2.28	325.0	Po.	β 8798
408	Pos. Med. 2164[2]	....	9.4	Ma	18 41 41	+59 28	2.28	325.0	Po.	
409	Lal. 34986	+10 3665	8.1	K5	18 43 46	+10 39	0.51	168.3	Comstock	
410	W.B. 18^h1295	+17 3729	9.0	......	18 44 29	+17 20	0.60	221.5	Po.	
411	Munich I 18180	+ 5 3993	9.3	Ma	18 53 7	+ 5 48	1.24	191.1	Po.	
412	A. G. Berlin A 7153	+18 3911	9.5	......	18 56 23	+18 57	0.58	209.7	Berlin A	
413	L.Bo. 2844	−20 5385	9.0	......	18 58 3	−20 35	0.72	204.6	Rist.	
414	Munich I 18816	+ 7 3967	9.2	K5:	19 2 14	+ 7 29	0.80	199.8	Po.	
415	Comp. C. to 17 Lyrae	....	11.3*	Ma	19 3 40	+32 21	1.75	49.5	β	
416	A.Oe. 19156	−21 5273	8.5	......	19 3 43	−21 37	0.50	205.0	Po.	
417	B.D. −0° 3676	− 0 3676	9.1	......	19 8 14	− 0 45	0.62	217.2	Roy	
418	Lal. 36245	+49 2959	6.2	G3	19 9 30	+49 40	0.62	348.0	Po.	β 9137
419	Lal. 36249	....	6.7	G2	19 9 31	+49 40	0.62	348.0	Po.	
420	Lal. 36647	+11 3833	5.5	G7	19 20 12	+11 44	0.96	48.8	Au.	
421	Lal. 36717	+24 3737	6.1	F4	19 21 17	+24 44	0.66	197.6	Au.	

422	Lal. 36872	−28° 6957	7.8	....	19h 26m 26s	−28° 13′	0″.76	177°.7	Po.	
423	Groom. 2875	+58 1929	6.4	K1	19 29 28	+58 23	0.66	232.6	Po.	
424	Lal. 37120	+32 3474	7.0	G2	19 29 44	+32 59	0.52	296.1	Po.	
425	σ Draconis	+69 1053	5.0	G5	19 32 33	+69 29	1.83	163.8	Po.	
426	α Aquilae	+ 8 4236	1.2	A5	19 45 54	+ 8 36	0.64	53.3	Au.	
427	Lal. 38100	−10 5238	6.3	F7	19 54 21	−10 13	0.51	217.1	Po.	
428	Lal. 38139	−12 5613	7.3	....	19 55 30	−12 31	0.50	225.0	Po.	
429	Lac. 8267	−67 3703	7.1	G5	19 55 34	−67 35	1.25	122.3	Po.	
430	Lal. 38287	+15 4026	7.0	G6	19 58 0	+15 20	0.60	198.4	Po.	
431	δ Pavonis	−66 3474	4.3	G5	19 58 55	−66 26	1.65	135.5	Po.	
432	Lal. 38380	+29 3872	6.0	K0	19 59 31	+29 38	0.86	127.4	Po.	
433	15 Sagittae	+16 4121	5.5	G0	19 59 37	+16 48	0.58	223.6	Po.	
434	Lal. 38383	+22 3908	7.0	K1	19 59 41	+23 5	1.39	227.4	Po.	
435	b¹ Cygni	+35 3959	5.5	K	20 2 39	+35 42	0.50	207.8	Boss	
436	Lac. 8362	−36 9037	6.6	K5	20 4 38	−36 21	1.70	164.7	Po.	
437	Lal. 38683	+15 4074	7.0	G9	20 6 34	+15 53	0.55	310.6	Po.	
438	Cp. St. St. 7242	−45 9899	8.8	....	20 6 45	−45 28	0.75	104.6	Cape	
439	Lal. 38711	−27 6972	7.2	G9	20 9 3	−27 20	1.28	100.8	Po.	
440	B.D. +76° 785	+76 785	9.0	....	20 13 51	+76 55	0.53	168.3	Greenwich	
441	A. G. Cambridge 6486	....	7.4	....	20 15 56	+55 5	0.81	270.0	Cambridge	β 10135
442	A. G. Cambridge 6487	+54 2329	6.0	A	20 15 57	+55 5	0.81	270.0	Cambridge	
443	Groom. 3150	+66 1281	6.2	F8	20 16 32	+66 32	0.57	57.2	Po.	
444	A.Oe. 20452	−21 5703	8.2	F5	20 17 42	−21 40	1.22	154.7	Po.	
445	Lal. 39704	+41 3799	6.7	G6	20 29 20	+41 33	0.50	337.9	Bonn	
446	B.D. +5° 4556	+ 5 4556	8.7	....	20 30 13	+ 5 47	0.51	135.3	β	
447	Lac. 8490	−60 7419	6.5	F8	20 31 46	−60 53	0.56	150.2	St.	
448	W.B. 20h802	+ 5 4570	9.0	....	20 33 40	+ 5 18	0.90	261.6	Sj.	
449	Lal. 39816	−24 7050	6.9	G	20 34 15	−24 8	0.62	48.9	Po.	
450	Lal. 39866	+ 4 4510	8.4	K5	20 34 33	+ 4 37	0.85	86.6	Po.	
451	Lal. 39854	−19 5889	8.2	....	20 35 6	−19 8	0.50	181.1	Po.	
452	Fed. 3562	+75 752	7.2	....	20 38 42	+75 14	0.64	33.0	Po.	
453	ε Cygni	+33 4018	2.6	K	20 42 10	+33 36	0.51	48.4	β	Sp. Bin.
454	η Cephei	+61 2050	3.7	K0	20 43 15	+61 27	0.82	6.3	Au.	
455	Lac. 8620	−44 9918	6.8	G	20 51 3	−44 29	1.12	208.1	Po.	
456	B.D. +61° 2068	+61 2068	8.4	....	20 51 16	+61 48	0.80	192.9	β	

TABLE I—*Continued*

No.	Name	B.D. or C.P.D.	Mag.	Spec.	α 1900	δ 1900	μ	p	Authority	Remarks
457	Fed. 3638	+74° 889	7.8	G4	20h 52m 22s	+74° 23′	0″.70	38°.0	Po.	
458	W.Mu.Z. 53.22	−34 8843	8.4	....	20 55 56	−34 27	1.31	172.6	Rist.	
459	Lac. 8625	−73 2192	6.6	F8	20 58 54	−73 34	0.60	129.6	Po.	
460	W.B. 20h1454	+ 2 4295	8.2	F3	20 59 6	+ 2 36	0.55	222.0	Po.	
461	Lal. 40844	+ 6 4741	8.8	K6	21 0 23	+ 6 41	0.57	177.0	Po.	
462	61¹ Cygni	+38 4343	5.0	K8	21 2 25	+38 15	5.18	51.4	Au.	β 10732
463	61² Cygni	+38 4344	5.3	K8	21 2 26	+38 15	5.12	53.7	Au.	
464	W.B. 21h97	+17 4519	7.3	F5	21 7 21	+17 21	0.91	188.2	Po.	
465	Fed. 3738	+73 925	8.6	....	21 8 48	+73 18	0.52	222.0	Küstner	
466	Lac. 8733	−61 6537	7.4	....	21 10 47	−61 46	0.67	130.7	Po.	
467	Lac. 8760	−39 8920	7.4	....	21 11 24	−39 15	3.46	249.4	Po.	
468	Lal. 41348	− 0 4195	8.5	....	21 12 52	− 0 15	0.50	112.4	β	
469	Lal. 41363	−26 7193	7.4	G5	21 13 59	−26 46	0.67	237.7	Po.	β 10881
470	Comp. to Lal. 41363	....	9.9	....	21 13 59	−26 46	0.67	237.7	Po.	
471	A.Oe. 21308	−20 6185	9.0	....	21 14 36	−20 15	0.80	192.3	Po.	
472	γ Pavonis	−65 3918	4.1	F8	21 18 11	−65 49	0.80	5.7	Po.	
473	W.B. 21h502	−13 5945	9.1	....	21 24 30	−12 56	1.06	105.3	Po.	
474	W.B. 21h594	+45 3561	7.5	....	21 26 0	+45 27	0.51	46.0	Rist.	
475	Cp. St. St. 7704	−50 11576	8.0	....	21 28 14	−50 14	0.62	259.8	Cape	
476	Lal. 42128	− 2 5588	8.7	....	21 33 2	− 2 45	0.50	303.0	Bossert	
477	A. G. Berlin B 8366	+24 4460	8.8	....	21 39 42	+24 53	0.68	213.3	Bellamy	
478	Lal. 42883	+29 4550	7.4	F7	21 54 15	+29 21	0.56	222.8	Po.	
479	ε Indi	−57 10015	6.7	K5	21 55 43	−57 12	4.71	123.9	Po.	
480	Lal. 43065	+ 4 4800	5.0	Kp	22 0 38	+ 4 34	0.50	263.6	Ps.†	
481	Lal. 43205	+52 3112	7.9	G8	22 3 5	+52 39	0.61	235.0	Po.	
482	W.B. 22h82	+22 4567	8.8	....	22 5 55	+22 15	0.60	264.2	Po.	
483	Lac. 9061	−41 9759	6.4	G	22 8 32	−41 51	0.92	142.5	Po.	
484	Lac. 9076	−54 10055	6.2	G	22 11 42	−54 7	0.80	147.3	Po.	
485	Lal. 43492	+12 4797	7.0	F9	22 12 15	+12 24	0.84	83.9	Po.	
486	ν Indi	−72 2690	6.0	F	22 16 2	−72 45	1.45	120.6	Po.	

† The P.M. given in Paris IV seems well founded. Still Bossert gives $\mu = 0''.13$, $p = 34^\circ.1$, Boss $\mu = 0''.14$, $p = 52^\circ.0$.

487	Cp. St. St. 7975	−51° 11806	8.6	......	22h 16m 17s	−51° 17′	1″.58	178°.9	Cape	
488	C.P.D. −30° 6641	−30 6641	7.9	......	22 23 35	−30 30	0.83	163.7	Union Obs.	
489	Krüger 60	+56 2783	9.0	Mb	22 24 28	+57 12	0.94	245.2	β	β 11761
490	Comp. B. to Krüger 60	......	12.0	......	22 24 28	+57 12	0.94	245.2	β	
491	B.D. +53° 2911	+53 2911	9.5	......	22 28 43	+53 16	1.23	83.1	Balanowsky	
492	Kli. 6256	+ 4 4879	8.3	......	22 30 32	+ 4 52	0.54	140.0	Rist.	
493	Münich I 31343	+ 1 4637	9.4	......	22 33 52	+ 2 0	0.55	99.5	Po.	
494	Lal. 44552	+11 4875	4.8	F5	22 41 42	+11 40	0.54	155.1	Po.	β 11957
495	Comp. to Lal. 44552	......	12.8	......	22 41 43	+11 40	0.54	155.1	β	
496	Cp. St. St. 8141	−42 9492	7.9	......	22 44 29	−42 1	0.51	240.0	Cape	
497	Lal. 44739	+ 9 5122	5.0	F	22 47 20	+ 9 18	0.50	85.4	Po.	
498	Lal. 44964	−23 8259	8.1	......	22 55 0	−23 4	0.92	270.4	Po.	
499	B.D. +68° 1345	+68 1345	8.3	......	22 55 9	+68 29	0.63	118.1	Greenwich	
500	Lal. 45028	− 4 5804	7.8	K2	22 56 39	− 4 23	0.54	122.8	Po.	
501	Lac. 9352	−36 9694	8.2	K	22 59 25	−36 26	7.00	80.5	Po.	
502	Fed. 4371	+67 1498	7.5	G3	23 1 10	+67 52	0.60	75.5	Po.	
503	Lal. 45292	− 3 5577	8.2	K5:	23 3 58	− 2 48	0.59	102.6	Po.	
504	Lac. 9396	−63 4862	7.1	G	23 7 57	−63 14	0.63	129.2	Po.	
505	Br. 3077	+56 2966	6.0	K7	23 8 28	+56 37	2.08	82.3	Au.	
506	Lal. 45455	− 9 6149	8.2	Fo	23 8 52	− 9 28	0.56	98.3	Po.	β 12234
507	Lal. 45456	− 9 6150	9.0	......	23 8 52	− 9 29	0.55	95.2	Po.	
508	W.B. 23h175	−14 6437	8.2	A2	23 11 54	−14 22	1.31	202.9	Po.	
509	Lal. 45565	+ 2 4648	3.8	K	23 11 59	+ 2 44	0.73	88.4	Au.	
510	Lal. 45638	+ 4 4994	8.5	G8	23 13 46	+ 4 52	0.52	103.6	Ps.	β 12290
511	Comp. to Lal. 45638	......	9.4	......	23 13 46	+ 4 52	0.52	103.6	β	
512	W.B. 23h257	+28 4562	8.5	......	23 14 59	+28 19	0.57	94.0	Po.	
513	Lal. 45755	+43 4445	7.3	G8	23 16 46	+43 33	0.67	70.8	Po.	
514	A. G. Cambridge 8232	+52 3440	7.0	......	23 20 57	+52 26	1.59	90.6	Cambridge	
515	A.Oe. 25685	+58 2605	7.5	K1	23 26 30	+58 37	1.08	85.2	Rist.	
516	d'Agelet 6348	+17 4946	8.0	......	23 31 0	+17 53	0.68	73.8	Po.	
517	Lac. 9537	−73 2299	7.4	......	23 33 42	−73 15	0.74	170.7	Po.	
518	Lal. 46351	+ 4 5035	4.2	F5	23 34 48	+ 5 5	0.56	141.5	Au.	
519	Lal. 46495	+57 2787	7.5	F8	23 38 32	+57 31	0.62	37.8	Po.	
520	W.B. 23h819	+28 4634	8.6	......	23 40 0	+29 0	0.85	86.7	Po.	
521	Lac. 9585	−42 9607	7.3	......	23 41 15	−42 7	0.86	172.6	Po.	

TABLE I—*Continued*

No.	Name	*B.D.* or *C.P.D.*	Mag.	Spec.	α 1900	δ 1900	μ	φ	Authority	Remarks
522	Cp. St. St. 8461	−48° 10958	7.4	......	23h 42m 7s	−48° 50′	0″.50	242°.1	Cape	
523	Lal. 46650	+ 1 4774	8.7	Ma	23 43 59	+ 1 52	1.39	135.9	Po.	
524	Munich I 32805	+ 2 4723	8.3	G7	23 44 56	+ 2 19	0.50	62.8	Po.	
525	Lal. 46867	+27 4642	7.0	......	23 49 55	+28 5	0.56	88.0	Po.	
526	Lal. 46972	+49 4291	6.7	......	23 53 3	+49 53	0.61	293.7	Bonn†	
527	B.D. +45° 4378	+45 4378	9.2	......	23 53 32	+46 10	0.53	93.4	Bonn	
528	A.Oe. 23166	−20 6684	7.3	......	23 54 17	−20 35	0.63	116.6	Po.	
529	Lal. 47118	+26 4734	6.1	G	23 56 57	+26 33	1.29	140.1	Po.	β 12701
530	Comp. to Lal. 47118	......	12.6	......	23 56 57	+26 33	1.29	140.1	β	β 12701
531	Gould 32416	−37 9435	8.8	......	23 59 31	−37 51	6.29	114.2	Po.	
532	Lal. 47207	+33 4828	6.3	Go	23 59 39	+34 6	0.78	84.1	Po.	
533	Anonymous	......	9.5*	......	23 59 54	+45 14	0.86	100.0	Furuhjelm	

† Porter gives for this star $\mu = 0''.26$, $p = 349°.1$, *Cin. Publ.*, **13**, 1893.

After this paper had been sent to the printer, *Circular No. 19 of the Union Observatory* appeared with the list by Innes of proper motion stars south of −19°. The following numbers of Innes' list should be included here, although for some of the stars the proper motion needs confirmation:

1[a]	33	42	73	74	80	99	137	173
177	224	227	296	357	397	415	416	417
427	429	430	452	542[a]	548[a]	638	653	690
744	748							

MOUNT WILSON SOLAR OBSERVATORY
January 25, 1915

PHOTOGRAPHIC AND PHOTO-VISUAL MAGNITUDES OF STARS NEAR THE NORTH POLE[1]

By FREDERICK H. SEARES

I. INTRODUCTION

The results here presented summarize an extended investigation of the photographic and photo-visual magnitude scales with the 60-inch reflector, which is soon to be published in detail as Vol. **3** of *Papers from the Mount Wilson Solar Observatory.*[2]

The investigation was begun in 1910, but various difficulties encountered in devising satisfactory methods of observation and reduction had first to be overcome, and it was not until 1912 that preliminary results were obtained. These were photographic magnitudes for the interval 10.5–17.5,[3] and, for the most part, were in excellent agreement with the Harvard results which, in the meantime, had been published in *H.C.*, No. 170.

The next step was the extension of the photographic scale in the direction of the brighter stars. The provisional magnitudes[4] were in good agreement with independent determinations by Parkhurst[5] and Schwarzschild,[6] but presented a serious divergence from the Harvard results, which thus far has not been satisfactorily explained.

For the extension of the scale to the fainter stars certain long-exposure plates, some of them taken with diaphragms and screens, were next reduced. The comparison of these results with those previously found in the region 10–15 gave material for the determination and discussion of systematic errors and led eventually to the scale finally adopted for the interval from the tenth to the twentieth magnitude.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 97.

[2] *Publications of the Carnegie Institution of Washington.*

[3] "Magnitude Scale of the Polar Sequence" (read at the fourteenth meeting of the Astronomical and Astrophysical Society of America), *Science*, N.S., **37**, 34, 1913.

[4] *Mt. Wilson Contr.*, No. 70; *Astrophysical Journal*, **38**, 241, 1913.

[5] "Yerkes Actinometry," *Astrophysical Journal*, **36**, 169, 1912.

[6] "Göttingen Aktinometrie," *Astron. Mitt. d. Kgl. Sternwarte zu Göttingen*, No. 14 B, p. 42, 1912.

Finally, the extension of the scale in the direction of the bright stars was thoroughly revised and strengthened by the inclusion of a large number of additional photographs.

The procedure for the determination of the photo-visual scale has been similar, but much more direct.

Although the methods used for the observations and reductions have been fully described in *Mt. Wilson Contr.*, No. 80,[1] it may be recalled that circular diaphragms and screens of wire gauze are generally employed for the reduced-intensity exposures; further, that the objects observed are grouped into (*a*) intermediate stars (magnitudes 10–18), (*b*) bright stars (brighter than *a*), (*c*) faint stars (fainter than *a*), for each of which the method of treatment is somewhat different. Finally, it has been found convenient to separate the observations of the intermediate stars into those of short and long exposure.

The distribution of the observational data is shown by Table I. The procedure followed in securing the photographs is described in *Mt. Wilson Contr.*, No. 70, p. 5, and No. 80, p. 16.[2]

TABLE I

SUMMARY OF PLATES USED

Star Group	Photographic Scale			Photo-visual Scale		
	Exposure	No. Plates	Apertures*	Exposure	No. Plates	Apertures
Intermediate—						
Short exposure	1^m to 11^m	15	60, 32, 14, 8, *G*, *g*, *S*	5^m and 20^m	2	60, 32, 14
Long exposure	30 to 60	14	60, 32, 14	45^m	2	60, 32
Bright	1 or 2	213	See Table V	3^m or 4^m	122	See Table VIII
Faint	3^h to 5^h	5	60	4^h	2	60

* *G* and *g* are screens of wire gauze, the former placed over the end of the tube, the latter in front of the plate; *S* is a 60° sector diaphragm. For further details of constants, etc., see *Mt. Wilson Contr.*, No. 80, p. 11.

II. PHOTOGRAPHIC SCALE FOR INTERMEDIATE STARS

As stated above, the reduction began with the short-exposure (SE) photographs of the intermediate stars. Magnitudes on an

[1] "Photographic Photometry with the 60-Inch Reflector of the Mount Wilson Solar Observatory," *Astrophysical Journal*, **39**, 307, 1914.

[2] *Astrophysical Journal*, **38**, 245, 1913; **39**, 322, 1914.

absolute scale were derived for each combination of apertures by the method described in *Mt. Wilson Contr.*, No. 80, p. 23.[1] The zero point was in each case determined by the magnitudes of *H.C.*, No. 170. The results for individual stars were combined into means, and the residuals were discussed for systematic errors depending upon the apertures. The degree of accordance for the different apertures and a comparison with *H.C.*, No. 170, are shown in Table IX, *Mt. Wilson Contr.*, No. 80, p. 31.[2]

The next step was the determination of magnitudes from the long-exposure (LE) photographs, the method of reduction being the same as before, except in the case of three plates which were reduced by a method described on p. 214.

All of the plates were measured with photometric scale III (*Mt. Wilson Contr.*, No. 80, p. 19[3]), which is approximately a uniform scale of magnitudes; but, as is the case with all such scales, local irregularities affect the individual readings. The residuals from the LE and SE plates afforded abundant material for the determination of these errors; not only were the scale-readings different for a given star on the SE and LE plates, but further diversity was introduced by the numerous images of varying size obtained with the screens and diaphragms. The residuals for the LE and SE plates were first discussed separately for fear that small differences in the magnitude-scales for the two series might influence the results. As the correction-curves thus obtained were practically identical, they were combined into a mean curve based upon about 2800 residuals. No star with less than 10 residuals was included in the discussion, and even then it was not used unless the scale-readings were well distributed over the scale.

All of the residuals were then corrected with the aid of the final curve, and the mean magnitudes for the different stars were revised. A comparison of the SE and LE results for the 58 stars included in both series is shown in the fifth column of Table II, the unit being 0.01 magnitude. The number of individual magnitudes entering into each group from the SE and LE plates, respectively, appears in the eighth column. A comparison of the mean magni-

[1] *Astrophysical Journal*, **39**, 329, 1914.

[2] *Ibid.*, p. 337, 1914.

[3] *Ibid.*, p. 325, 1914.

tudes from all the plates with those of *H.C.*, No. 170, is given in the next to the last column.

TABLE II

RESULTS FROM SE AND LE PLATES

Group	Mean Mag.	Scale-Reading		LE−SE	Rel. Weight	No. Stars	No. Mags.	Comp. with *H.C.* No. 170	
		SE	LE					MW−HC	No. Stars
1......	10.6	......	......	+6	23	4	136, 29	+2	3
2......	12.6	......	......	0	81	6	282,115	−2	8
3......	13.4	7.8	2.8	+1	123	12	355,202	+1	5
4......	14.3	10.7	6.0	0	101	12	219,203	+3	3
5......	14.8	12.5	7.9	+2	104	9	228,210	−4	5
6......	15.5	14.6	10.4	+5	50	7	83,142	−6	5
7......	16.6	17.9	14.5	+10	43	8	74,112	−22	8
Totals						58	1377,1013		37

The weight of the first LE−SE difference is small, and the difference itself is not surprisingly large. The next four differences show a close accordance in the two series of results. The last two, however, require further examination. Turning to the Harvard comparison, we find the same systematic divergence for the faint stars that characterized the preliminary results from the SE plates.[1]

It was suspected that the origin of the small systematic difference in the SE and LE results would be found in the corrections applied to the original scale-readings to reduce them to the center of the plate. With the 60-inch reflector these corrections are large, and their direct determination, especially for the faint stars, is difficult. As the distance error for the diaphragm apertures is negligible, or at least very small, it is evident that incorrect values for the full aperture must systematically affect the calculated scale of magnitudes.

The corrections which had been used were those resulting from the provisional investigation described in *Mt. Wilson Contr.*, No. 80, p. 20.[2] This gave a linear relation between the correction and the distance from the center of the plate, and further, for the full aperture, a relation between error and size of image defined by the

[1] *Mt. Wilson Contr.*, No. 70, p. 4; No. 80, p. 31; *Astrophysical Journal*, **38**, 244, 1913; **39**, 337, 1914.

[2] *Astrophysical Journal*, **39**, 326, 1914.

curve on p. 22 of that article. Fortunately, the data from the photographs under discussion were sufficient to permit a thorough examination of the question. The number of separate results for each star was large, and, in general, the range in the distance from the center of the plate was considerable, for the centering of the field was different on different photographs.

The residuals for the full-aperture results from about a hundred stars were arranged in groups, each covering one interval of scale-reading and 2 mm of distance. About 2000 residuals were used although only those from stars having numerous and well-distributed observations were included. In order to reduce accidental irregularities, overlapping means were formed for the groups. The results were then plotted, those relating to a single scale-reading defining a curve whose abscissae were distances from the center of the plate, and whose ordinates were corrections which, applied to the individual magnitudes, would remove any systematic dependence upon brightness and distance; in other words, would reduce the individual results to the mean scale. The mean scale, however, is not the true scale, for, as just remarked, the use of an erroneous correction for distance has affected the result.

Two corrections were therefore applied to the calculated magnitudes: (*a*) the ordinate δD of the correction-curve, corresponding to the position and size of the image, which reduced the individual results to the mean scale; (*b*) a scale correction, δm, to reduce from the mean scale to that which would have been obtained had the true distance-correction been used. The final solution could also have been obtained by repeating the calculation from the beginning with the revised distance-correction, but this would have been a very laborious operation.

An examination of the curves giving the values of δD shows that the original distance-correction was substantially correct, except for very large and very small images for which the results have been overcorrected. The curves further show that for all the intermediate and fainter images the assumption of a linear relation between distance-correction and distance is permissible. For the brighter images, however, an appreciable deviation from this relation is now apparent.

To determine the extent to which the scale has been affected by the use of the original distance-correction, it is necessary to know how much the correction was in error. This may be determined by displacing the δD-curves parallel to themselves in a vertical direction until they pass through the origin, for the correction must be zero at the center of the plate.[1] The ordinates of the displaced curves are the required errors.

The determination of the influence of these errors upon the magnitude-scale is now a simple matter. We have only to assume a series of hypothetical observations s and s_1 representing the scale-readings for a full aperture and a diaphragm exposure, respectively. These we transform into magnitudes by the usual process. We then correct the full-aperture readings s by the amount of the error in the original distance-correction and repeat the calculation. The difference in the two series of magnitudes is the required scale correction δm, which is conveniently expressed as a function of the scale-reading.

Two points, however, must be noted: First, in reducing the hypothetical observations, we must use for the constant of the diaphragm a value corresponding to the real observations, taking care, further, to select for the scale-readings values such that the differences $\Delta s = s_1 - s$ agree approximately with the observations. Secondly, the change in the distance-correction by which the values of s are modified before the repetition of the reduction to magnitudes must correspond to the mean distance of the stars actually observed.

It is further tacitly assumed that the distance-correction for the reduced aperture is negligible, or at least requires no revision. As a matter of fact, the discussion of about a thousand residuals for the 32- and 14-inch diaphragms showed only minute deviations, which, although systematic, have been disregarded because they are without influence upon the scale.

[1] At first sight, errors of focus would seem to require a modification of this statement; but for a reflector, images off the axis are always larger than central images. In other words, the increase in the images due to the aberrations of the mirror is large as compared with that due to curvature of the field. Moreover, in the present case, errors of focus play a very minor part, for with the diaphragm and screen plates the exposures were short, or moderate at most, and the focus was always carefully watched.

With regard to the first of the foregoing points, it may be remarked that several different apertures, with correspondingly different reduction constants, have been employed in reducing the plates. To take this circumstance into account, it is only necessary to reduce the hypothetical observations with the mean of the reduction constants actually used.

It was thus found that for scale-readings less than 12 no correction of the magnitude scale was required. For larger scale-readings the corrections are given in the second column of Table III. These results apply only to the plates taken with diaphragms. Those with which the wire screens were used require no scale correction whatever. Since the distance-correction with the screen is the same as that without the screen,[1] an erroneous correction, used for both full and reduced intensity images, can have no influence upon the *mean* scale, that is, the scale established for a large number of stars of each degree of brightness uniformly scattered over the plate. Individual magnitudes will be in error, but these compensate each other in the mean. The matter is easily tested with the aid of hypothetical observations as above. For this purpose the reduced intensity scale-readings, before the repetition of the calculation, should receive the same modification as those of the full aperture. The two series of magnitudes will then differ only by a constant.

It has been assumed that these remarks also apply to the three plates taken with the 60° sector diaphragm. As this method of reducing the intensity has been but little used, its distance-correction has not been investigated. It seems probable that the correction would not be unlike that for the full aperture, and, in the absence of definite information, this assumption has been accepted as valid.

Before correcting the several thousand individual magnitudes in the manner indicated, information was desired as to whether this procedure would account for the systematic difference between the SE and LE plates shown in Table II. This information was, however, already available, for an examination of the results on the assumption that the scale error depended only on the size of the image had shown what that error must be. Its value was derived by a step-by-step process based on the data in Table II.

[1] *Mt. Wilson Contr.*, No. 80, p. 21; *Astrophysical Journal*, **39**, 327, 1914.

Since for scale-readings less than 12 the differences LE—SE are zero, it follows from the foregoing assumption that, as far as this limit, both scales are correct. The differences for Groups 5 and 6 of Table II are therefore the errors of the SE magnitude-scale at points whose photometric scale-readings are 12.5 and 14.6. We thus know the error of the LE scale for reading 14.5 (Group 7), and with the aid of the corresponding LE—SE difference find the error for reading 17.9.

The results of the calculation thus outlined are shown in the third column of Table III alongside those derived from the revision

TABLE III

ERROR OF PROVISIONAL SCALE

SCALE-READING	δm	
	DC	SE and LE
	mag.	mag.
12	+0.02	+0.01
13	.03	.02
14	.04	.04
15	.05	.05
16	.06	.07
17	.10	.10
18	.16	.14
19	0.26	0.23

of the distance-correction. As the two series of values are practically identical, we infer that the difference between the scales from the SE and LE plates may be attributed entirely to errors in the original distance-correction.

Proceeding to the revision of the individual magnitudes, the two corrections δD and δm were applied to each residual. The mean values were then revised and the results for the SE and LE plates again compared. The accordance of the two scales (Table IV) is now all that can be desired and indicates that there are no remaining errors of any consequence which depend upon the exposure time or the size of the images. The comparison with *H.C.*, No. 170, in the last column of Table IV is less satisfactory, however. The differences MW—HC are but little changed as compared with those in Table II, and the results for the faint stars which now

appear in the reduction show that the divergence beginning at magnitude 15 continues to increase and becomes ultimately very large.

It has been remarked (p. 208) that three of the LE plates received special treatment. As the exposure time for these was one hour, they are of great importance in establishing the scale for the fainter stars and a more detailed account of their reduction is desirable.

The necessity for special treatment arose from the fact that the reduced intensity exposures were obtained with a 6-inch diaphragm whose constant is 4.81 mag. With constants as large as this, the usual method[1] of deriving the scale cannot safely be applied. The

TABLE IV

FINAL RESULTS FOR SE AND LE PLATES

MW Mean Mag.	LE−SE	Rel. Weight	MW−HC
	mag.		mag.
10.6	+0.018	36	−0.05
11.7	+ .007	49	− .05
12.8	− .007	76	+ .03
13.4	.000	100	+ .02
14.0	+ .023	74	+ .03
14.3	− .026	71	+ .03
14.8	+ .004	98	− .03
15.5	+ .034	77	− .06
16.8	+0.017	34	− .17
17.9	....	....	− .39
18.5	....	....	− .53
19.1	....	....	−0.87

range of scale-reading for the secondary images of stars with measurable full-intensity images is too small to permit the use of the ordinary interpolation process.

On this account, the scale, as far as the fifteenth magnitude, was assumed to be known. The adopted magnitudes were plotted against the scale-readings of the primary images, and at the same time, the adopted magnitudes, less the amount of the reduction constant, were plotted against the readings of the corresponding secondary images. Smooth curves were drawn, from which were read magnitudes for all of the images shown. The scale for the faint stars thus found is not, of course, independently derived, for

[1] *Mt. Wilson Contr.*, No. 80, p. 23; *Astrophysical Journal*, **39**, 329, 1914.

the method merely transfers an adopted scale to the region of the fainter objects. The results, however, are in close agreement[1] with those from other LE plates, which, because of smaller constants, could be independently reduced. The zero point is of course that of the adopted scale.

III. PHOTOGRAPHIC SCALE FOR FAINT STARS

The magnitudes derived from the three LE plates just discussed carry the scale somewhat below the limit (magnitude 18) which is regarded as separating the intermediate from the faint stars, but as they depend upon diaphragm exposures, it has been convenient to group them with the intermediate stars. On the other hand, one plate of moderately short exposure, because of the manner in which it was taken, appears among the faint-star plates. We now turn to the discussion of this latter portion of the data.

The plates for the faint stars usually received two exposures, both with the full aperture, one long and one short. The method of reduction, which involves an extrapolation, though a fairly reliable one, is described in *Mt. Wilson Contr.*, No. 80, pp. 5, 26.[2] The scale for the intermediate stars must be known. As this was the case for the objects brighter than the eighteenth magnitude, mean results for about 160 stars, none including less than 8 or 10 individual values, were available for the reduction. As each of the five plates was reduced with the revised distance-correction no subsequent corrections were required.

The results extend the photographic scale to the twentieth magnitude and include values for the brightness of a large number of objects not shown by the other plates. They also afford additional values for many of the intermediate stars, which have been combined with the original magnitudes to reduce the effect of accidental errors. The revised mean magnitudes, together with the magnitudes of the additional stars, have been entered in the catalogue.[3]

[1] See residuals for Plates 196, 200, and 204 in Table XII.

[2] *Astrophysical Journal*, **39**, 311, 332, 1914.

[3] With a few exceptions no results appear in the catalogue given in Table IX unless both photographic and photo-visual magnitudes have been determined.

IV. PHOTOGRAPHIC SCALE FOR BRIGHT STARS

The method here applied has been fully described and illustrated in *Mt. Wilson Contr.*, No. 70,[1] and little in the way of detail need be added. It involves a transference of the scale for the intermediate stars to the region of the brighter objects. The operation is repeated with a number of different apertures, and the results for each give a scale for the bright stars which is homogeneous with the adopted scale unless there is some unsuspected form of error; the slope of the scale found with each aperture, independently of error in the reduction constant, is the same as that of the adopted scale. An error in the constant affects the calculated magnitudes by a fixed amount; hence their relative values should be correct. Further, since the separate scales overlap, a comparison of results for the various apertures controls the errors of the constants.

As stated above, the data for the bright stars in *Mt. Wilson Contr.*, No. 70,[2] have been strengthened by the inclusion of additional plates. Further, six stars fainter than the tenth magnitude were added to the list in order that the results by the method used for the bright stars might overlap considerably those derived from the diaphragm and screen plates for the intermediate stars. Finally, the earlier plates were entirely re-reduced, the revised distance-correction and the magnitudes whose derivation has been described in Section 2 being used for this purpose.

The results, now based upon 662 individual magnitudes as against 295 in the original investigation, are given in Table V which corresponds to Table II in *Mt. Wilson Contr.*, No. 70. The second column gives the final magnitudes referred to the zero point defined by HC magnitudes between 10 and 15, which thus far has been consistently used. As before, the headings indicate the apertures and the approximate reduction constants used in establishing the separate scales. "Various" includes several different apertures which were only occasionally employed. The tabular values are the residuals, referred to the means in the second column, of the results for each star as found with each aperture. The number of values included in each residual is indicated by the attached number

[1] *Astrophysical Journal*, **38**, 241, 1913.

[2] *Loc. cit.*

TABLE V

PHOTOGRAPHIC MAGNITUDES OF BRIGHT STARS

No.	MW Pg. Mag.	40 1.1	32 2.0	14 3.0	*G* 3.1	9 3.9	6 4.8	32+*G* 5.0	14+*G* 6.0	G_1 6.1	9+*G* 7.0	6+*G* 7.9	14+2*G* 9.2	Various	MW *Minus* HC
1*s*	2.14	...	...	...	...	...	...	...	...	...	...	...	−7 (8)	+2 (32)	−57
1	3.99	...	...	...	...	...	...	...	...	...	− 9 (4)	− 2 (4)	+3 (6)	+6 (6)	−48
2	4.90	...	...	...	...	...	...	...	−15 (5)	+ 3 (3)	+ 4 (4)	+18 (3)	...	...	−34
3	5.43	...	...	...	...	...	...	...	− 3 (6)	− 5 (5)	+ 2 (6)	+ 8 (3)	+6 (2)	...	−31
4	5.51	...	...	...	...	...	...	...	− 4 (6)	−16 (4)	+ 5 (7)	+14 (4)	+2 (2)	...	−40
5	6.05	...	...	...	...	...	−16 (5)	+ 6 (5)	+ 5 (5)	0 (4)	+ 5 (6)	...	...	...	−34
2*s*	6.05	...	...	...	...	−19 (3)	−13 (6)	− 2 (4)	+16 (6)	+ 2 (7)	+ 4 (7)	...	...	...	−33
1*r*	6.21	...	...	...	...	...	− 4 (2)	...	+ 2 (9)	−13 (8)	+ 8 (6)	+16 (2)	...	...	−48
3*s*	6.24	...	...	...	...	−26 (1)	−13 (4)	− 5 (3)	+ 7 (5)	− 8 (3)	+13 (6)	...	...	...	−30
6	6.71	...	...	...	...	+ 1 (3)	+ 5 (4)	+10 (2)	− 2 (3)	− 8 (4)	...	...	...	...	−27
7	7.01	...	...	...	...	−14 (5)	− 3 (5)	+10 (4)	+ 5 (7)	+ 3 (5)	...	...	...	...	−17
2*r*	7.54	...	+21 (1)	−12 (2)	−11 (4)	− 4 (3)	+ 1 (3)	−13 (3)	+19 (3)	+ 9 (3)	...	...	...	...	−19
8	7.92	...	...	−13 (5)	− 1 (5)	+ 3 (5)	− 3 (6)	+18 (3)	+11 (6)	− 6 (6)	...	...	...	...	−18
9	8.48	...	+22 (4)	+ 2 (2)	− 3 (6)	+ 7 (4)	− 2 (6)	−20 (4)	...	...	...	...	...	...	−22
3*r*	8.56	...	−22 (2)	− 1 (4)	+12 (4)	− 1 (4)	0 (2)	+ 4 (2)	...	...	...	...	...	+1 (1)	− 6
10	8.72	...	+ 1 (5)	+ 9 (3)	+ 2 (3)	− 9 (4)	+ 3 (3)	− 3 (3)	...	...	...	...	...	...	−17
4*r*	8.82	...	−20 (2)	+ 6 (5)	+ 8 (3)	+ 5 (5)	− 1 (3)	−20 (2)	...	...	...	...	...	...	−15
11	9.33	...	− 4 (6)	− 6 (7)	+ 7 (7)	+ 2 (6)	...	+ 2 (2)	...	...	...	...	...	...	− 9
12	9.69	−10 (4)	− 8 (5)	− 7 (5)	+ 7 (5)	+11 (6)	...	...	...	...	...	...	...	...	− 4
5*r*	9.73	0 (4)	−13 (6)	− 8 (6)	+11 (5)	+21 (3)	...	...	...	...	...	...	...	...	− 5
4*s*	9.85	+ 1 (3)	0 (4)	− 4 (4)	+ 4 (4)	+ 2 (4)	...	...	...	...	...	...	...	...	−14
6*r*	10.06	−10 (6)	0 (4)	− 1 (6)	+10 (6)	+ 4 (4)	...	...	...	...	...	...	...	...	−11
13	10.13	0 (4)	0 (6)	− 8 (5)	+ 8 (4)	...	...	...	...	...	...	...	...	...	− 4
7*r*	10.51	+ 6 (2)	− 1 (2)	+ 4 (1)	−14 (1)	...	...	...	...	...	...	...	...	...	− 6
14	10.52	− 4 (2)	− 2 (3)	+ 4 (3)	+ 2 (2)	...	...	...	...	...	...	...	...	...	0
15	10.90	−14 (4)	− 8 (4)	+14 (4)	+ 8 (4)	...	...	...	...	...	...	...	...	...	− 4
6*s*	10.98	−10 (3)	− 4 (3)	+14 (1)	+16 (2)	...	...	...	...	...	...	...	...	...	+ 1
8*r*	11.12	−11 (5)	+ 2 (5)	+14 (5)	+ 8 (2)	...	...	...	...	...	...	...	...	−12 (3)	+ 6
16	11.21	0 (6)	− 1 (7)	...	...	...	...	...	...	...	...	...	...	+ 6 (2)	− 5
17	11.53	− 8 (8)	+ 8 (8)	...	...	...	...	...	...	...	...	...	...	...	+ 4
18	11.90	− 4 (8)	+ 5 (8)	...	...	...	...	...	...	...	...	...	...	...	− 2
Systematic deviations		−6 (59)	−1 (85)	−1 (68)	+5 (67)	0 (60)	−5 (49)	−1 (37)	+4 (61)	−4 (52)	+5 (46)	+10 (16)	−1 (18)	+ 2 (44)	

in parentheses.[1] The weighted mean residuals appearing at the bottom are the systematic deviations of the results for each aperture from the mean of all. These quantities are closely related to the errors of the reduction constants.

It is unnecessary to repeat here the details of the discussion undertaken in *Mt. Wilson Contr.*, No. 70, as the results are essentially the same. The following, however, may be noted:

1. No marked progression in the residuals appears in any of the columns. The parallelism of the constituent scales with the mean scale is therefore close.

2. The systematic deviations at the bottom of the table are small; hence the errors in the reduction constants are also small and probably have had but little influence upon the mean scale.

3. The re-reduction and the inclusion of new data have diminished the accidental errors, but have not materially altered the scale. The divergence from *H.C.*, No. 170, remains substantially as before.

4. Since the constituent scales are sensibly parallel, they must all show the same divergence from the results of *H.C.*, No. 170.

A comparison of the overlapping portion of the scale here established with that for the intermediate stars is shown in the first half of Table VI. In view of the fact that the IS results are here subject to some uncertainty because of large distance error, the agreement is as good as can be expected.

There remains still to be considered the influence of the apparent magnitude to which the bright stars have been reduced in determining their real magnitudes.[2] This is shown in the first part of Table VII. The second column gives the mean residual for all the results derived from apparent magnitudes within the limits shown in the first column. Thus the 69 values for bright stars found by reducing to apparent magnitudes between 9.5 and 11.0 are fainter by 0.08 magnitude, on the average, than the final magnitudes in the second column of Table V. This difference is the zero-point

[1] Note that the algebraic signs of the residuals are here reversed as compared with those of *Mt. Wilson Contr.*, No. 70. Thus for star 12, the residual −10 for the 40-inch diaphragm indicates that the mean of the four values found with this aperture is 9.79.

[2] *Mt. Wilson Contr.*, No. 70, pp. 16–22; *Astrophysical Journal*, **38**, 256–262, 1913.

error of this particular portion of the results relative to the mean of them all. Its origin will be discussed at a later time. Now it need only be noted that, while obviously systematic, the dependence upon apparent magnitude is small and probably without influence upon the mean scale for the bright stars.

TABLE VI

COMPARISON OF OVERLAPPING SCALES FOR BRIGHT AND INTERMEDIATE STARS

Star No.	Photographic				Photo-visual			
	BS	IS	No.	B−I	BS	IS	No.	B−I
13........	10.13	....	19, 0	....	10.37	10.46	11, 5	− 9
14........	10.52	10.59	10, 47	− 7	10.52	10.68	12, 6	−16
15........	10.90	10.76	16, 14	+14	10.92	10.97	9, 1	− 5
16........	11.21	11.22	15, 28	− 1	11.19	11.40	11, 5	−21
17........	11.53	11.43	16, 27	+10	11.27	11.37	8, 5	−10
18........	11.90	11.85	16, 33	+ 5	11.92	11.92	8, 6	0
7*r*.......	10.51	10.55	6, 28	− 4	9.91	9.96	18, 10	− 5
8*r*.......	11.12	10.92	20, 12	+20	10.44	10.54	12, 5	−10
5*s*.......	....	10.69	0, 60	....	10.04	10.16	17, 11	−12
6*s*.......	10.98	....	9, 0	....	10.78	10.72	9, 4	+ 6
Means..				+ 5				− 8

TABLE VII

DEPENDENCE UPON APPARENT MAGNITUDE

Range of Apparent Mag.	Photographic		Photo-visual	
	Residual	No.	Residual	No.
9.5–11.0........	−8	69	−2*	19
11.0–11.5........	−2	72	−6	68
11.5–12.0........	−1	92	−1	55
12.0–12.5........	0	132	+3	76
12.5–13.0........	−1	83	0	62
13.0–13.5........	+3	125	+4	60
13.5–14.0........	+5	66	+2	27
14.0–14.7........	+6	23	....	....
Totals.......		662		367

* The range of apparent magnitude for this value is 10.1–10.8.

V. THE PHOTO-VISUAL SCALE

The photo-visual scale has been determined in precisely the same manner as the photographic; but the operations have been simpler and the labor much less, for fewer plates were used and the irregu-

TABLE VIII

PHOTO-VISUAL MAGNITUDES OF BRIGHT STARS

No.	MW Pv. Mag.	60 0	40 1.1	32 2.0	14 3.0	G 3.1	9 3.9	40+G 4.2	6 4.8	14+G 6.0	G_2 6.1	9+G 7.0	40+G_2 7.2	Various	MW *Minus* HC
1s	2.11													0 (23)	−1
1	4.40											−2 (2)	−2 (2)	+1 (5)	−4
1r	5.12									−14 (2)	−8 (3)	+8 (2)		+13 (3)	−14
2	5.31									0 (2)	−17 (3)	+10 (1)	0 (2)	+14 (3)	−7
3	5.59								−7 (2)	−4 (2)	−1 (3)	+5 (4)			−3
4	5.87									−23 (1)	+9 (3)	+9 (2)	−4 (2)	−14 (1)	+1
2s	6.36								−18 (3)	+15 (3)	−3 (3)	+20 (1)			+8
3s	6.38								−18 (2)	+5 (2)	−9 (3)	+18 (3)			+5
2r	6.38								−9 (3)	+14 (2)	−3 (3)	+13 (1)	−2 (3)		−17
5	6.50								−15 (2)	+10 (2)	−1 (4)	+5 (2)			+7
6	7.08						−6 (2)		−2 (3)	−1 (3)	+12 (2)				+7
7	7.55								−2 (5)	+8 (4)	−8 (3)				+11
3r	7.59				−4 (1)		−4 (2)	+4 (2)	+4 (2)	−13 (1)	+19 (1)			−2 (2)	+2
8	8.16			−9 (4)	−7 (3)	+13 (3)	+6 (4)								+19
4r	8.29				−4 (1)	+18 (2)	−4 (1)	0 (2)	+4 (1)					−16 (2)	+3
5r	8.68			0 (4)	−7 (2)	+10 (2)	+4 (2)	−6 (2)							+1
9	8.84				+4 (2)	−2 (2)	−1 (2)	−8 (2)	+10 (2)					0 (2)	+23
10	9.10			−16 (2)	+9 (3)	+2 (3)	−8 (2)	+11 (2)							+16
6r	9.24			−21 (3)	+6 (3)	+9 (3)	−7 (1)	+10 (2)							−1
11	9.56			−2 (2)	−4 (2)	−1 (3)	+20 (1)	−4 (2)							+26
12	9.83			−4 (4)	−1 (4)	+4 (4)									+29
4s	9.86			−4 (3)	−2 (4)	−3 (2)	+3 (1)	+24 (1)							+28
7r	9.91		−13 (4)	+1 (6)	+5 (6)	+6 (2)									+7
5s	10.04		−12 (4)	+2 (5)	+5 (6)	+6 (2)									+18
13	10.37		−7 (4)	+6 (2)	−10 (2)	+13 (3)									+12
8r	10.44	0 (3)	−1 (4)	−4 (4)	+23 (1)										+5
14	10.52	+2 (2)	+1 (3)	−13 (3)	+15 (2)	+4 (2)									+8
6s	10.78	+2 (3)	0 (3)	−1 (3)											+3
15	10.92		+2 (4)	−5 (4)	+18 (1)										+14
16	11.19	−6 (3)	+3 (4)	+2 (4)											+12
17	11.27	+12 (4)	−5 (3)	−31 (1)											+9
18	11.92	+1 (4)	+5 (3)	−16 (1)											−1
Systematic deviations		+2 (19)	−3 (36)	−5 (55)	+2 (43)	+6 (33)	0 (18)	+2 (15)	−6 (25)	+3 (24)	−3 (31)	+9 (18)	−2 (9)	+1 (41)	

larities of the photometric scale and the errors of the distance-correction tables had previously been investigated.

The intermediate stars require no comment beyond the statement that the provisional zero point was that defined by the visual magnitudes of *H.C.*, No. 170, which are fainter than 9.8. The results for the bright stars are given in Table IX, which is similar in arrangement to Table V. The mean magnitudes in the second column depend upon 367 individual values.

Although the visual scale of *H.C.*, No. 170, and the Mount Wilson photo-visual scale coincide at the sixth and the twelfth magnitudes, there are important differences at intervening points. An appreciable color equation also makes its appearance, for it will be noted that the differences MW−HC are systematically smaller for the red stars than for the white.

The accordance of the overlapping portions of the scales for the bright and the intermediate stars is shown by the second half of Table VI. The systematic difference of 0.08 magnitude is probably due to an error in the IS scale, which in this region is somewhat uncertain.

Finally, the dependence of the scale for the bright stars upon the apparent magnitudes from which the individual values have been derived appears in Table VII. Here the residuals are again slightly systematic, but satisfactory.

VI. DETERMINATION OF THE ZERO POINTS

The zero-point corrections have been determined in such a way that both photographic and photo-visual magnitudes of the white stars near the sixth magnitude have the same mean value as the corresponding visual magnitudes of *H.C.*, No. 170. The objects actually used in determining the corrections were Nos. 2–6 and 2*s* and 3*s*. As only two of these are of spectrum A0, an allowance for color was made in the case of the photographic scale. The resulting corrections are +0.40 magnitude for the photographic scale, and −0.03 magnitude for the photo-visual.

VII. THE CATALOGUE

The complete catalogue includes 645 objects. Photographic magnitudes have been derived for 617 of these and photo-visual

magnitudes for 339. The catalogue in Table IX, however, contains only 329, for with the exception of Polar Sequence stars no object has been entered unless both photographic and photo-visual magnitudes have been determined.

For convenience the Polar Sequence stars appear at the beginning of the table, arranged in the order of their numbers as given in *H.C.*, No. 170. The numbers of the remaining stars, unless a letter is attached, are those of *Harvard Annals*, **48**, Part I. Those with letters are faint objects near the *H.A.* star of the same number. Their rectangular co-ordinates for 1900 are given in Table X.

The magnitudes in the second and third columns of Table IX were obtained by applying to the preliminary values the zero-point corrections given above. For the stars appearing in Table VI, the weighted means of the IS and BS results were the values thus corrected and entered in the catalogue. The number of separate determinations entering into each photographic and photo-visual magnitude, respectively, is shown in the fifth column. The remaining columns contain comparisons of the Mount Wilson photographic scale with that of Harvard[1] and of Greenwich[2] and with the results of Dziewulski[3] obtained with the 80-cm refractor of the Potsdam Observatory.

VIII. SYSTEMATIC DIFFERENCES

The systematic differences affecting the results for the bright stars have already been shown in Tables V and VIII. Those for the photographic magnitudes of the intermediate stars which depend on the method of reducing the intensity are given in Table XI. The agreement is much better than it was before the revision of the distance-correction.[4] The circular diaphragms give practically identical results, but the screens still show divergences of a few hundredths of a magnitude. The last two columns of the table

[1] *H.C.*, No. 170, 1912.

[2] *Monthly Notices*, R.A.S., **74**, 40, 1913.

[3] *Astronomische Nachrichten*, **198**, 65, 1914.

[4] *Mt. Wilson Contr.*, No. 80, p. 31, Table IX; *Astrophysical Journal*, **39**, 337, 1914. Note that the signs of the residuals must be reversed to make them comparable with Table XI of this paper.

TABLE IX

CATALOGUE OF MAGNITUDES

No.	Magnitude		Color Index	No. Obs.	MW *Minus* HC	MW *Minus* Gr	MW *Minus* Dz	MW *Minus* HH_W	MW *Minus* Gr_1	MW *Minus* Dz_1
	Pg	Pv								
1.....	4.39	4.37	0.02	20, 9	− 8	.....	.....	−16	.....	.....
2.....	5.30	5.28	0.02	15, 11	+ 6	.....	.....	− 1	.....	.....
3.....	5.83	5.56	0.27	22, 11	+ 9	.....	.....	− 1	.....	.....
4.....	5.91	5.84	0.07	23, 9	0	.....	.....	− 8	.....	.....
5.....	6.45	6.47	−0.02	25, 10	+ 6	.....	.....	− 2	.....	.....
6.....	7.11	7.05	0.06	16, 10	+13	.....	.....	+ 4	.....	.....
7.....	7.41	7.52	−0.11	26, 12	+23	.....	.....	+16	.....	.....
8.....	8.32	8.13	0.19	36, 14	+22	.....	.....	+11	.....	.....
9.....	8.88	8.81	0.07	26, 12	+18	.....	.....	+ 9	.....	.....
10.....	9.12	9.07	0.05	21, 12	+23	+29	+27	+15	+ 5	− 4
11.....	9.73	9.53	0.20	28, 10	+31	.....	.....	+20	.....	.....
12.....	10.09	9.80	0.29	25, 12	+36	.....	.....	+24	.....	.....
13.....	10.53	10.37	0.16	19, 16	+36	+27	.....	+26	0	.....
14.....	10.98	10.54	0.44	57, 18	+46	+36	+38	+33	+ 1	+10
15.....	11.22	10.89	0.33	30, 10	+28	+27	+19	+17	− 5	−10
16.....	11.62	11.23	0.39	43, 16	+36	+36	+38	+25	+ 2	+ 9
17.....	11.87	11.28	0.59	43, 13	+38	+40	+27	+22	+ 1	0
18.....	12.27	11.89	0.38	49, 14	+35	+30	+22	+22	− 3	− 7
19.....	12.69	12.28	0.41	78, 12	+41	+37	+37	+28	+ 3	+ 8
20.....	13.02	12.51	0.51	86, 12	+43	+41	+37	+29	+ 4	+ 9
21.....	13.33	12.48	0.85	37, 12	+51	+47	+16	+29	+ 1	−10
22.....	13.44	12.81	0.63	45, 11	+39	+42	+24	+22	+ 2	− 3
23.....	13.60	13.10	0.50	80, 12	+40	+40	+32	+25	+ 3	+ 4
24.....	13.93	13.33	0.60	71, 12	+43	+40	+33	+28	+ 1	+ 6
25.....	14.08	13.60	0.48	78, 12	+35	+33	+25	+22	− 3	− 3
26.....	14.64	13.72	0.92	74, 12	+45	+49	+28	+27	+ 1	+ 3
27.....	14.91	14.33	0.58	61, 7	+36	+35	+33	+22	− 4	+ 5
28.....	15.27	14.54	0.73	40, 7	+30	+34	+22	+15	− 9	− 5
29.....	15.82	15.21	0.61	40, 6	+30	+32	+ 8	+16	− 7	−19
30.....	16.18	15.44	0.74	34, 5	+28	.....	+12	+14	.....	−15
31.....	16.41	15.62	0.79	45, 6	+33	.....	+34	+18	.....	+ 8
32.....	16.76	15.58	1.18	33, 3	+28	.....	+46	+12	.....	+22
33.....	17.06	15.97	1.09	32, 3	+24	.....	.....	+ 7	.....	.....
34.....	17.24	16.29	0.95	24, 2	+13	.....	.....	− 1	.....	.....
35.....	17.63	16.94	0.69	20, 2	+27	.....	.....	+13	.....	.....
36.....	17.78	16.80	0.98	18, 2	+17	.....	.....	+ 4	.....	.....
37.....	18.01	16.81	1.20	16, 2	+21	.....	.....	+ 7	.....	.....
38.....	18.20	17.05	1.15	15, 2	+ 3	.....	.....	−10	.....	.....
39.....	18.58	17.13	1.45	14, 2	+ 5	.....	.....	− 9	.....	.....
40.....	18.87	17.29	1.58	11, 2	− 2	.....	.....	−15	.....	.....
41.....	19.02	17.47	1.55	8, 2	−11	.....	.....	−24	.....	.....
42.....	19.18	.....	.....	8	−36	.....	.....	−44	.....	.....
43.....	19.53	.....	.....	4	−55	.....	.....	−63	.....	.....
44.....	19.59	.....	.....	3	−71	.....	.....	−79	.....	.....
45.....	19.80	.....	.....	1	−80	.....	.....	−88	.....	.....
46.....	19.82	.....	.....	2	−114	.....	.....	−122	.....	.....
1r....	6.61	5.09	1.52	27, 10	− 8	.....	.....	−26	.....	.....
2r....	7.94	6.35	1.59	22, 12	+21	.....	.....	+ 3	.....	.....
3r....	8.96	7.56	1.40	19, 11	+34	.....	.....	+17	.....	.....
4r....	9.22	8.26	0.96	20, 9	+25	.....	.....	+11	.....	.....

TABLE IX—*Continued*

No.	Magnitude		Color Index	No. Obs.	MW *Minus* HC	MW *Minus* Gr	MW *Minus* Dz	MW *Minus* HH_W	MW *Minus* Gr_1	MW *Minus* Dz_1
	Pg	Pv								
5*r*...	10.13	8.65	1.48	24, 12	+35	.....	.....	+16	.....	.....
6*r*...	10.46	9.21	1.25	26, 12	+29	.....	.....	+11	.....	.....
7*r*...	10.94	9.90	1.04	34, 28	+37	+40	+ 9	+22	−11	−16
8*r*...	11.44	10.44	1.00	32, 17	+38	+50	.....	+24	0	.....
10*r*...	.....	12.03	.....	5	.....	.....	.....	.....	.....	.....
11*r*...	13.22	12.06	1.16	79, 12	+39	+56	+21	+25	+ 2	− 3
12*r*...	13.84	12.46	1.38	82, 12	+50	+65	+26	+31	+ 5	+ 3
1*s*...	2.54	2.08	0.46	40, 23	−17	.....	.....	−25	.....	.....
2*s*...	6.45	6.33	0.12	33, 10	+ 7	.....	.....	− 2	.....	.....
3*s*...	6.64	6.35	0.29	22, 10	+10	.....	.....	− 1	.....	.....
4*s*...	10.25	9.83	0.42	19, 11	+26	.....	.....	+17	.....	.....
5*s*...	11.09	10.06	1.03	60, 28	+41	+45	+22	+26	− 6	− 3
6*s*...	11.38	10.73	0.65	9, 13	+41	+48	+10	+26	+ 7	−17
7*s*...	12.61	12.10	0.51	70, 12	+30	+36	+36	+16	− 1	+ 8
8*s*...	14.49	13.78	0.71	50, 12	+43	+37	+27	+27	− 5	0
9*s*...	14.75	13.85	0.90	66, 12	+42	+42	+29	+25	− 5	+ 3
10*s*...	15.29	14.49	0.80	45, 7	+41	+42	+31	+25	− 3	+ 5
11*s*...	15.31	14.35	0.96	63, 10	+40	+37	+27	+22	−12	+ 2
12*s*...	15.33	14.69	0.64	61, 7	+36	+31	+21	+21	− 9	− 6
13*s*...	15.54	14.54	1.00	43, 3	+45	+55	+25	+27	+ 5	0
14*s*...	15.99	15.07	0.92	47, 7	+38	+36	+ 3	+21	−12	−22
15*s*...	16.57	15.71	0.86	41, 5	+29	.....	.....	+15	.....	.....
16*s*...	16.86	15.50	1.36	36, 4	+28	.....	.....	+11	.....	.....
17*s*...	17.19	15.89	1.30	27, 2	+22	.....	.....	+ 5	.....	.....
18*s*...	17.94	16.91	1.03	19, 2	+ 8	.....	.....	+ 5	.....	.....
19*s*...	18.16	16.95	1.21	15, 2	−14	.....	.....	−32	.....	.....
20*s*...	18.60	17.19	1.41	13, 2	+ 4	.....	.....	− 9	.....	.....
21*s*...	18.66	17.33	1.33	12, 2	− 1	.....	.....	−20	.....	.....
22*s*...	18.75	17.13	1.62	11, 2	0	.....	.....	−18	.....	.....
23*s*...	18.70	17.41	1.29	12, 2	−18	.....	.....	−38	.....	.....
24*s*...	18.88	17.34	1.54	12, 2	0	.....	.....	− 9	.....	.....
25*s*...	18.84	17.38	1.46	10, 2	−18	.....	.....	−31	.....	.....
26*s*...	18.99	.....	.....	9	−30	.....	.....	−38	.....	.....
27*s*...	19.08	17.43	1.65	9, 2	−22	.....	.....	−30	.....	.....
28*s*...	19.23	.....	.....	8	−33	.....	.....	−41	.....	.....
29*s*...	19.28	.....	.....	6	−76	.....	.....	−84	.....	.....
30*s*...	19.52	.....	.....	3	−66	.....	.....	−74	.....	.....
31*s*...	19.49	.....	.....	3	−69	.....	.....	−77	.....	.....
32*s*...	19.56	.....	.....	4	−62	.....	.....	−70	.....	.....
33*s*...	19.68	.....	.....	4	−56	.....	.....	−64	.....	.....
34*s*...	19.70	.....	.....	2	−60	.....	.....	−68	.....	.....
35*s*...	19.86	.....	.....	3	−60	.....	.....	−68	.....	.....
36*s*...	19.48	.....	.....	3	−108	.....	.....	−116	.....	.....
37*s*...	19.65	.....	.....	2	−93	.....	.....	−101	.....	.....
38*s*...	20.10	.....	.....	1	−90	.....	.....	−98	.....	.....
119....	17.38	15.97	1.41	2, 1	.....	.....	.....	.....	.....	.....
119*a*...	17.88	16.40	1.48	1, 1	.....	.....	.....	.....	.....	.....
124....	16.50	15.09	1.41	4, 3	.....	.....	.....	.....	.....	.....
125....	15.12	14.37	0.75	2, 5	.....	+70	+76	.....	+27	+50
125*a*...	16.90	15.91	0.99	1, 2	.....	.....	.....	.....	.....	.....
126....	15.58	14.65	0.93	2, 4	.....	+29	+23	.....	−19	− 2
127....	14.35	13.31	1.04	6, 11	.....	+65	+51	.....	+14	+26

TABLE IX—*Continued*

No.	Magnitude		Color Index	No. Obs.	MW *Minus* HC	MW *Minus* Gr	MW *Minus* Dz	MW *Minus* HH_W	MW *Minus* Gr_t	MW *Minus* Dz_t
	Pg	Pv								
127*a*...	16.78	15.81	0.97	4, 1	......	......	......	......	......	......
127*b*...	18.40	16.96	1.44	3, 1	......	......	......	......	......	......
127*c*...	17.01	15.50	1.51	8, 2	......	......	......	......	......	......
127*d*...	18.29	17.05	1.24	2, 2	......	......	......	......	......	......
127*e*...	18.24	16.97	1.27	2, 2	......	......	......	......	......	......
128....	15.88	13.87	2.01	1, 2	......	+61	+48	......	−16	+29
130....	15.26	14.21	1.05	2, 9	......	+63	+57	......	+12	+32
134....	14.43	13.54	0.89	6, 10	......	+64	+54	......	+17	+28
134*a*...	17.52	16.22	1.30	4, 2	......	......	......	......	......	......
134*b*...	17.96	16.72	1.24	2, 2	......	......	......	......	......	......
139....	15.30	13.96	1.34	2, 7	......	+48	+26	......	−11	+ 3
142....	14.60	13.71	0.89	2, 11	......	+56	+45	......	+ 9	+19
143....	16.35	15.51	0.84	7, 2	......	......	......	......	......	......
146....	14.52	13.56	0.96	2, 10	......	+70	+56	......	+21	+31
151....	13.72	12.58	1.14	29, 11	......	+53	+22	......	− 1	− 2
151*a*...	18.66	17.21	1.45	3, 2	......	......	......	......	......	......
151*b*...	18.55	17.15	1.40	3, 2	......	......	......	......	......	......
151*c*...	18.10	16.88	1.22	3, 2	......	......	......	......	......	......
151*d*...	18.21	16.93	1.28	3, 2	......	......	......	......	......	......
151*e*...	18.45	17.08	1.37	3, 2	......	......	......	......	......	......
152....	14.56	13.76	0.80	21, 12	......	+45	+31	......	0	+ 5
152*a*...	18.38	16.63	1.75	5, 2	......	......	......	......	......	......
152*b*...	17.56	16.74	0.82	7, 2	......	......	......	......	......	......
152*c*...	17.15	16.09	1.06	10, 2	......	......	......	......	......	......
152*d*...	18.66	17.38	1.28	2, 1	......	......	......	......	......	......
152*e*...	18.52	17.12	1.40	2, 2	......	......	......	......	......	......
154....	14.95	14.36	0.59	8, 9	......	+29	+39	......	−10	+12
154*a*...	17.78	16.59	1.19	3, 2	......	......	......	......	......	......
154*b*...	18.11	17.04	1.07	4, 1	......	......	......	......	......	......
154*c*...	18.40	17.13	1.27	3, 1	......	......	......	......	......	......
158....	15.10	14.57	0.53	16, 5	......	+14	+12	......	−23	−16
158*a*...	18.77	17.09	1.68	3, 2	......	......	......	......	......	......
158*b*...	18.88	17.20	1.68	3, 1	......	......	......	......	......	......
159....	15.20	14.50	0.70	16, 4	......	+24	+32	......	−18	+ 5
159*a*...	17.80	16.34	1.46	5, 1	......	......	......	......	......	......
159*b*...	18.13	16.64	1.49	5, 2	......	......	......	......	......	......
159*g*...	19.03	17.10	1.93	2, 1	......	......	......	......	......	......
160....	16.68	15.54	1.14	11, 2	......	......	......	......	......	......
160*a*...	18.73	16.95	1.78	3, 2	......	......	......	......	......	......
163....	15.13	13.93	1.20	1, 3	......	+16	− 7	......	−39	−31
164....	16.02	15.03	0.99	18, 5	......	......	+11	......	......	−14
164*a*...	18.73	17.13	1.60	3, 1	......	......	......	......	......	......
169....	16.85	16.02	0.83	13, 2	......	......	......	......	......	......
169*a*...	18.46	16.95	1.51	6, 2	......	......	......	......	......	......
172....	13.85	12.24	1.61	2, 1	......	+71	+28	......	+ 5	+ 7
176....	14.33	13.81	0.52	36, 12	......	+26	+26	......	−11	− 2
176*a*...	16.87	16.07	0.80	12, 2	......	......	......	......	......	......
176*c*...	18.22	17.15	1.07	3, 2	......	......	......	......	......	......
183....	16.53	15.64	0.89	21, 3	......	......	......	......	......	......
184*a*...	17.18	16.03	1.15	3, 2	......	......	......	......	......	......
184*b*...	17.14	16.14	1.00	3, 2	......	......	......	......	......	......
184*c*...	18.52	16.82	1.70	3, 2	......	......	......	......	......	......
186....	16.34	15.54	0.80	22, 3	......	......	......	......	......	......

TABLE IX—*Continued*

No.	Magnitude		Color Index	No. Obs.	MW *Minus* HC	MW *Minus* Gr	MW *Minus* Dz	MW *Minus* HH_W	MW *Minus* Gr_1	MW *Minus* Dz_1
	Pg	Pv								
188....	16.29	15.27	1.02	24, 4	.....	+67	+31	.....	+16	+ 6
190*a*...	17.56	16.57	0.99	15, 2	.....	.....	.....	.....	.....	.....
190*b*...	18.10	16.78	1.32	16, 2	.....	.....	.....	.....	.....	.....
190*c*...	17.87	16.95	0.92	12, 2	.....	.....	.....	.....	.....	.....
190*d*...	17.99	16.73	1.26	11, 2	.....	.....	.....	.....	.....	.....
190*f*...	19.19	17.21	1.98	3, 1	.....	.....	.....	.....	.....	.....
191*a*...	19.17	17.53	1.64	3, 1	.....	.....	.....	.....	.....	.....
202....	16.12	15.41	0.71	27, 4	.....	.....	+21	.....	.....	− 6
202*a*...	18.80	17.21	1.59	11, 2	.....	.....	.....	.....	.....	.....
205....	15.97	15.08	0.89	11, 4	.....	+53	+28	.....	+ 6	+ 2
207....	16.69	15.73	0.96	10, 2	.....	.....	.....	.....	.....	.....
208....	16.67	15.93	0.74	12, 2	.....	.....	.....	.....	.....	.....
208*a*...	18.65	17.07	1.58	3, 2	.....	.....	.....	.....	.....	.....
208*b*...	18.69	17.17	1.52	3, 2	.....	.....	.....	.....	.....	.....
212*d*...	17.81	16.88	0.93	17, 2	.....	.....	.....	.....	.....	.....
212*e*...	17.04	16.31	0.73	18, 2	.....	.....	.....	.....	.....	.....
213....	16.81	15.75	1.06	20, 3	.....	.....	.....	.....	.....	.....
214....	15.39	14.66	0.73	9, 7	.....	+22	+23	.....	−21	− 4
214*c*...	18.53	16.79	1.74	3, 2	.....	.....	.....	.....	.....	.....
214*d*...	17.59	16.23	1.36	3, 2	.....	.....	.....	.....	.....	.....
214*e*...	17.88	16.73	1.15	3, 2	.....	.....	.....	.....	.....	.....
214*f*...	18.15	16.47	1.68	3, 2	.....	.....	.....	.....	.....	.....
214*g*...	18.06	16.69	1.37	3, 2	.....	.....	.....	.....	.....	.....
215....	15.47	13.69	1.78	10, 3	.....	+60	+30	.....	−11	+10
217....	16.55	15.51	1.04	10, 4	.....	.....	.....	.....	.....	.....
218....	15.47	14.11	1.36	17, 8	.....	+47	+27	.....	−13	+ 4
218*a*...	16.82	15.59	1.23	12, 4	.....	.....	.....	.....	.....	.....
218*b*...	17.20	16.02	1.18	11, 2	.....	.....	.....	.....	.....	.....
219*a*...	17.61	16.63	0.98	17, 2	.....	.....	.....	.....	.....	.....
219*b*...	17.53	16.20	1.33	17, 2	.....	.....	.....	.....	.....	.....
219*c*...	17.85	16.81	1.04	13, 2	.....	.....	.....	.....	.....	.....
219*d*...	18.69	16.95	1.74	12, 2	.....	.....	.....	.....	.....	.....
219*e*...	19.03	17.50	1.53	9, 1	.....	.....	.....	.....	.....	.....
219*f*...	18.26	16.93	1.33	13, 2	.....	.....	.....	.....	.....	.....
219*g*...	18.53	16.99	1.54	11, 2	.....	.....	.....	.....	.....	.....
219*h*...	19.11	17.50	1.61	3, 1	.....	.....	.....	.....	.....	.....
224....	16.49	15.48	1.01	22, 4	.....	.....	.....	.....	.....	.....
226....	14.93	14.23	0.70	46, 7	.....	+35	+30	.....	− 7	+ 3
226*a*...	18.45	16.79	1.66	10, 2	.....	.....	.....	.....	.....	.....
226*b*...	18.30	16.92	1.38	11, 2	.....	.....	.....	.....	.....	.....
226*c*...	18.73	16.93	1.80	10, 2	.....	.....	.....	.....	.....	.....
226*d*...	18.79	17.11	1.68	11, 1	.....	.....	.....	.....	.....	.....
226*e*...	18.81	17.02	1.79	9, 1	.....	.....	.....	.....	.....	.....
227*a*...	17.69	16.49	1.20	14, 2	.....	.....	.....	.....	.....	.....
227*b*...	18.15	16.99	1.16	12, 2	.....	.....	.....	.....	.....	.....
227*c*...	18.51	17.29	1.22	10, 2	.....	.....	.....	.....	.....	.....
227*d*...	17.93	16.67	1.26	17, 2	.....	.....	.....	.....	.....	.....
229....	16.34	15.57	0.77	24, 3	.....	.....	.....	.....	.....	.....
229*a*...	18.23	16.99	1.24	16, 2	.....	.....	.....	.....	.....	.....
229*b*...	17.80	16.69	1.11	16, 2	.....	.....	.....	.....	.....	.....
244....	16.22	15.47	0.75	13, 4	.....	.....	.....	.....	.....	.....
244*a*...	17.93	16.68	1.25	8, 2	.....	.....	.....	.....	.....	.....
244*b*...	18.75	16.83	1.92	1, 1	.....	.....	.....	.....	.....	.....

TABLE IX—*Continued*

No.	Magnitude		Color Index	No. Obs.	MW *Minus* HC	MW *Minus* Gr	MW *Minus* Dz	MW *Minus* HH_W	MW *Minus* Gr_1	MW *Minus* Dz_1
	Pg	Pv								
247....	16.43	15.89	0.54	21, 2	.....	.....	.....	.....	.....	.....
248*a*...	16.30	15.23	1.07	4, 3	.....	.....	.....	.....	.....	.....
254*a*...	18.71	17.64	1.07	8, 1	.....	.....	.....	.....	.....	.....
256....	14.67	13.86	0.81	50, 11	.....	+56	+29	.....	+11	+ 3
258....	16.07	15.22	0.85	6, 4	.....	+58	+28	.....	+12	+ 2
258*a*...	17.45	16.17	1.28	5, 2	.....	.....	.....	.....	.....	.....
277....	15.30	14.61	0.69	62, 7	.....	+21	+22	.....	−21	− 5
277*a*...	18.54	17.04	1.50	10, 1	.....	.....	.....	.....	.....	.....
279*a*...	17.98	16.87	1.11	7, 2	.....	.....	.....	.....	.....	.....
279*b*...	18.47	17.07	1.40	8, 2	.....	.....	.....	.....	.....	.....
279*c*...	17.73	16.27	1.46	7, 2	.....	.....	.....	.....	.....	.....
279*d*...	18.44	17.21	1.23	6, 2	.....	.....	.....	.....	.....	.....
279*e*...	18.60	16.88	1.72	6, 2	.....	.....	.....	.....	.....	.....
279*f*...	17.80	16.75	1.05	7, 2	.....	.....	.....	.....	.....	.....
283....	14.87	13.50	1.37	28, 3	.....	+54	+21	.....	− 6	− 2
286....	15.97	14.96	1.01	10, 4	.....	+48	.....	.....	− 2	.....
288*a*...	16.63	15.29	1.34	23, 5	.....	.....	.....	.....	.....	.....
288*b*...	18.53	17.45	1.08	13, 2	.....	.....	.....	.....	.....	.....
288*c*...	18.10	16.81	1.29	13, 2	.....	.....	.....	.....	.....	.....
288*d*...	19.06	17.53	1.53	8, 1	.....	.....	.....	.....	.....	.....
289*a*...	17.91	16.84	1.07	12, 2	.....	.....	.....	.....	.....	.....
289*b*...	18.77	17.25	1.52	11, 1	.....	.....	.....	.....	.....	.....
289*c*...	18.76	17.21	1.55	11, 1	.....	.....	.....	.....	.....	.....
289*d*...	17.44	16.29	1.15	14, 2	.....	.....	.....	.....	.....	.....
289*e*...	17.52	16.55	0.97	12, 2	.....	.....	.....	.....	.....	.....
292*a*...	17.96	16.82	1.14	5, 2	.....	.....	.....	.....	.....	.....
292*b*...	17.27	16.16	1.11	5, 2	.....	.....	.....	.....	.....	.....
292*c*...	17.49	16.77	0.72	3, 1	.....	.....	.....	.....	.....	.....
292*d*...	18.82	16.46	2.36	2, 1	.....	.....	.....	.....	.....	.....
295....	15.57	14.93	0.64	32, 5	.....	+31	+23	.....	− 9	− 4
295*a*...	17.97	16.95	1.02	14, 2	.....	.....	.....	.....	.....	.....
295*b*...	18.09	16.88	1.21	13, 2	.....	.....	.....	.....	.....	.....
295*c*...	18.85	17.53	1.32	10, 1	.....	.....	.....	.....	.....	.....
295*d*...	19.26	17.68	1.58	3, 1	.....	.....	.....	.....	.....	.....
297....	15.81	14.79	1.02	5, 3	.....	+41	+17	.....	−10	− 8
297*a*...	18.56	17.11	1.45	2, 1	.....	.....	.....	.....	.....	.....
297*b*...	18.10	16.93	1.17	3, 1	.....	.....	.....	.....	.....	.....
299....	16.59	15.83	0.76	22, 2	.....	.....	.....	.....	.....	.....
301....	16.23	15.57	0.66	26, 2	.....	.....	+12	.....	.....	−15
302*a*...	16.91	15.97	0.94	21, 2	.....	.....	.....	.....	.....	.....
302*b*...	18.24	16.89	1.35	14, 2	.....	.....	.....	.....	.....	.....
302*c*...	19.02	17.50	1.52	9, 1	.....	.....	.....	.....	.....	.....
302*d*...	18.97	17.33	1.64	6, 1	.....	.....	.....	.....	.....	.....
311....	15.00	14.36	0.64	53, 7	.....	+30	+32	.....	−10	+ 5
311*a*...	17.22	16.05	1.17	14, 2	.....	.....	.....	.....	.....	.....
311*b*...	17.73	16.68	1.05	5, 2	.....	.....	.....	.....	.....	.....
319....	14.44	13.55	0.89	40, 3	.....	+49	+29	.....	+ 2	+ 3
323*a*...	17.55	16.55	1.00	17, 2	.....	.....	.....	.....	.....	.....
323*b*...	18.96	17.17	1.79	8, 1	.....	.....	.....	.....	.....	.....
323*c*...	18.66	17.01	1.65	10, 2	.....	.....	.....	.....	.....	.....
323*e*...	18.81	17.18	1.63	10, 2	.....	.....	.....	.....	.....	.....
323*f*...	18.90	17.05	1.85	10, 1	.....	.....	.....	.....	.....	.....

TABLE IX—*Continued*

No.	Magnitude		Color Index	No. Obs.	MW *Minus* HC	MW *Minus* Gr	MW *Minus* Dz	MW *Minus* HH_W	MW *Minus* Gr_I	MW *Minus* Dz_I
	Pg	Pv								
323*h*...	19.03	17.08	1.95	8, 1	.....	.....	.....	.....	.....	.....
324*a*...	17.95	16.72	1.23	17, 2	.....	.....	.....	.....	.....	.....
324*b*...	18.57	17.05	1.52	13, 2	.....	.....	.....	.....	.....	.....
329....	14.32	13.34	0.98	38, 3	.....	+47	+31	.....	− 2	+ 6
334....	15.20	14.42	0.78	70, 7	.....	+30	+20	.....	−14	− 6
335....	16.11	15.11	1.00	23, 4	.....	+35	.....	.....	−15	.....
335*a*...	17.69	16.67	1.02	13, 2	.....	.....	.....	.....	.....	.....
335*b*...	18.77	17.33	1.44	7, 1	.....	.....	.....	.....	.....	.....
336....	14.92	13.97	0.95	26, 5	.....	+42	+27	.....	− 7	+ 2
336*a*...	17.31	16.27	1.04	5, 2	.....	.....	.....	.....	.....	.....
336*b*...	17.27	16.41	0.86	5, 2	.....	.....	.....	.....	.....	.....
337*a*...	18.50	16.84	1.66	14, 2	.....	.....	.....	.....	.....	.....
337*c*...	18.82	17.38	1.44	11, 2	.....	.....	.....	.....	.....	.....
337*d*...	18.98	17.34	1.64	10, 1	.....	.....	.....	.....	.....	.....
338....	14.72	13.79	0.93	28, 3	.....	+45	+28	.....	− 3	+ 3
341....	15.16	13.92	1.24	26, 3	.....	+36	+25	.....	−20	+ 1
342....	14.86	14.09	0.77	26, 3	.....	+24	+27	.....	−20	+ 1
343....	16.44	15.01	1.43	23, 5	.....	.....	.....	.....	.....	.....
343*a*...	17.94	16.83	1.11	16, 2	.....	.....	.....	.....	.....	.....
343*b*...	18.86	17.27	1.59	9, 1	.....	.....	.....	.....	.....	.....
343*c*...	17.16	16.59	0.57	17, 2	.....	.....	.....	.....	.....	.....
343*d*...	18.46	16.89	1.57	10, 2	.....	.....	.....	.....	.....	.....
343*e*...	18.56	16.95	1.61	11, 2	.....	.....	.....	.....	.....	.....
345....	13.79	12.01	1.78	58, 11	.....	+66	+17	.....	− 5	− 3
350....	11.01	10.64	0.37	46, 12	.....	+37	+40	.....	+ 4	+11
350*a*...	17.39	16.59	0.80	8, 1	.....	.....	.....	.....	.....	.....
350*b*...	17.72	16.79	0.93	5, 2	.....	.....	.....	.....	.....	.....
350*c*...	18.19	16.64	1.55	5, 2	.....	.....	.....	.....	.....	.....
358....	15.22	14.11	1.11	26, 2	.....	+23	+15	.....	−30	− 9
362....	13.13	12.31	0.82	86, 12	.....	+53	+31	.....	+ 8	+ 5
362*a*...	16.39	15.61	0.78	19, 2	.....	.....	.....	.....	.....	.....
362*b*...	17.47	16.57	0.90	15, 2	.....	.....	.....	.....	.....	.....
362*c*...	18.15	16.48	1.67	13, 2	.....	.....	.....	.....	.....	.....
362*d*...	17.96	16.75	1.21	14, 2	.....	.....	.....	.....	.....	.....
362*e*...	18.47	16.99	1.48	11, 2	.....	.....	.....	.....	.....	.....
362*f*...	18.78	17.23	1.55	10, 2	.....	.....	.....	.....	.....	.....
362*h*...	18.74	17.29	1.45	10, 2	.....	.....	.....	.....	.....	.....
363*a*...	17.94	16.41	1.53	14, 2	.....	.....	.....	.....	.....	.....
363*b*...	18.36	17.05	1.31	13, 1	.....	.....	.....	.....	.....	.....
364....	16.44	15.49	0.95	22, 3	.....	.....	.....	.....	.....	.....
364*a*...	17.20	16.35	0.85	17, 2	.....	.....	.....	.....	.....	.....
364*b*...	18.01	16.99	1.02	12, 1	.....	.....	.....	.....	.....	.....
364*c*...	16.88	16.11	0.77	17, 1	.....	.....	.....	.....	.....	.....
364*d*...	17.55	16.71	0.84	13, 1	.....	.....	.....	.....	.....	.....
364*e*...	18.24	16.82	1.42	10, 1	.....	.....	.....	.....	.....	.....
364*f*...	18.54	17.24	1.30	10, 1	.....	.....	.....	.....	.....	.....
364*i*...	18.39	17.05	1.34	10, 1	.....	.....	.....	.....	.....	.....
365*c*...	18.85	17.11	1.74	11, 1	.....	.....	.....	.....	.....	.....
365*d*...	19.04	17.20	1.84	6, 1	.....	.....	.....	.....	.....	.....
365*e*...	18.97	17.34	1.63	9, 1	.....	.....	.....	.....	.....	.....
368....	15.78	14.48	1.30	2, 3	.....	+46	+24	.....	−12	+ 1
368*a*...	17.17	16.09	1.08	1, 1	.....	.....	.....	.....	.....	.....

TABLE IX—*Continued*

No.	Magnitude		Color Index	No. Obs.	MW *Minus* HC	MW *Minus* Gr	MW *Minus* Dz	MW *Minus* HH_W	MW *Minus* Gr_1	MW *Minus* Dz_1
	Pg	Pv								
370*c*...	16.80	15.73	1.07	22, 1	......	......	......	......	......	......
372....	16.09	15.52	0.57	10, 3	......	......	......	......	......	......
372*a*...	17.40	16.62	0.78	3, 1	......	......	......	......	......	......
372*b*...	17.82	16.63	1.19	5, 2	......	......	......	......	......	......
372*c*...	17.31	16.69	0.62	4, 1	......	......	......	......	......	......
378....	14.14	12.74	1.40	54, 5	......	+ 68	+20	......	+ 7	− 3
386*c*...	18.17	16.77	1.40	12, 1	......	......	......	......	......	......
386*e*...	17.72	16.85	0.87	15, 1	......	......	......	......	......	......
389....	13.57	12.83	0.74	43, 8	......	+ 47	+32	......	+ 4	+ 5
391....	14.63	13.85	0.78	38, 6	......	+ 48	+42	......	+ 4	+16
401....	14.53	13.61	0.92	36, 3	......	+ 43	+26	......	− 5	+ 1
403....	14.51	13.75	0.76	41, 3	......	+ 29	+25	......	−15	− 1
410*a*...	16.96	16.18	0.78	17, 1	......	......	......	......	......	......
424....	14.51	13.64	0.87	29, 3	......	+ 38	+38	......	− 8	+12
426....	13.83	13.33	0.50	28, 3	......	+ 47	+29	......	+10	+ 1
427....	13.27	12.07	1.20	33, 5	......	+ 62	+35	......	+ 7	+11
439....	15.29	13.49	1.80	1, 3	......	+118	+89	......	+46	+69

show the mean results for these two methods of reducing the intensity. The deviations are in all cases referred to the mean scale, which depends upon 42 separate determinations.

As the lower limit of Table XI is only 17.1, some indication of the accordance of the results for the faint stars is desirable. This is shown in Table XII, which gives the mean deviations of groups of stars for each of the long-exposure plates. In no case is there a serious divergence from the mean scale. Some of the average deviations at the bottom of the table appear to be large; but it must be recalled that they include the errors of the scales derived from the separate plates for a range of 9 or 10 magnitudes. The number of magnitudes from each plate and the diaphragms used for the reduced-intensity exposures are also shown at the bottom of the table.

Although the photo-visual results are based upon a much smaller number of plates than the photographic, their relative weights are more nearly equal than the number of observations would indicate. This arises from the higher precision of the individual magnitudes from the photo-visual plates. Thus the average deviation of a single photographic magnitude, based on the results for stars fainter than the tenth magnitude and including the effect of

TABLE X

RECTANGULAR CO-ORDINATES FOR 1900

No.	X	Y	No.	X	Y	No.	X	Y
119a....	−755″	−79″	219a.....	−329″	−181″	302d.....	+230″	−339″
125a....	−750	−446	219b.....	−304	−156	311a.....	+193	−549
127a....	−695	+36	219c.....	−332	−312	311b.....	+171	−703
127b....	−664	−76	219d.....	−270	−160	323a.....	+178	+242
127c....	−651	−70	219e.....	−254	−168	323b.....	+163	+214
127d....	−670	−101	219f.....	−288	−214	323c.....	+118	+254
127e....	−667	−112	219g.....	−322	−240	323e.....	+245	+194
134a....	−649	−365	219h.....	−342	−285	323f.....	+268	+190
134b....	−697	−280	226a.....	−311	+251	323h.....	+288	+228
151a....	−544	−93	226b.....	−357	+268	324a.....	+207	−6
151b....	−625	−35	226c.....	−211	+196	324b.....	+162	+78
151c....	−636	−7	226d.....	−172	+174	335a.....	+247	−524
151d....	−619	0	226e.....	−228	+286	335b.....	+296	−599
151e....	−607	+17	227a.....	−268	−412	336a.....	+187	−820
152a....	−608	−252	227b.....	−209	−394	336b.....	+210	−788
152b....	−608	−321	227c.....	−178	−402	337a.....	+289	−62
152c....	−619	−234	227d.....	−206	−265	337c.....	+248	−87
152d....	−630	−258	229a.....	−243	−73	337d.....	+248	−31
152e....	−622	−364	229b.....	−231	−85	343a.....	+302	−465
154a....	−538	−574	244a.....	−181	−599	343b.....	+301	−460
154b....	−478	−530	244b.....	−200	−685	343c.....	+328	−468
154c....	−536	−580	248a.....	−80	−954	343d.....	+362	−506
158a....	−524	−316	254a.....	−79	−292	343e.....	+354	−455
158b....	−556	−277	258a.....	−140	−791	350a.....	+335	−685
159a....	−648	+145	277a.....	−78	−571	350b.....	+240	−710
159b....	−543	+171	279a.....	+45	−690	350c.....	+283	−755
159g....	−505	+233	279b.....	−94	−645	362a.....	+482	−352
160a....	−536	+57	279c.....	−57	−691	362b.....	+487	−194
164a....	−531	−199	279d.....	−39	−712	362c.....	+466	−182
169a....	−520	−31	279e.....	+49	−693	362d.....	+457	−154
176a....	−487	−210	279f.....	+84	−682	362e.....	+455	−224
176c....	−415	−333	288a.....	−2	−240	362f.....	+486	−276
184a....	−460	−649	288b.....	+27	−254	362h.....	+372	−310
184b....	−422	−836	288c.....	+70	−288	363a.....	+351	+4
184c....	−409	−633	288d.....	+89	−210	363b.....	+398	+101
190a....	−432	+152	289a.....	+42	+186	364a.....	+458	−462
190b....	−364	+137	289b.....	−35	+193	364b.....	+503	−481
190c....	−452	+169	289c.....	−28	+224	364c.....	+542	−460
190d....	−449	+261	289d.....	+2	+353	364d.....	+488	−554
190f....	−376	+150	289e.....	+51	+311	364e.....	+548	−511
191a....	−392	−146	292a.....	−20	−854	364f.....	+452	−513
202a....	−355	−22	292b.....	+109	−780	364i.....	+540	−377
208a....	−376	−434	292c.....	+52	−912	365c.....	+410	−115
208b....	−346	−395	292d.....	+122	−836	365d.....	+384	−138
212d....	−227	+130	295a.....	+68	−530	365e.....	+374	−185
212e....	−333	+196	295b.....	+37	−489	368a.....	+413	−796
214c....	−241	−833	295c.....	+26	−429	370c.....	+311	+215
214d....	−310	−849	295d.....	+11	−406	372a.....	+443	−691
214e....	−358	−830	297a.....	+100	−914	372b.....	+411	−692
214f....	−345	−783	297b.....	+102	−905	372c.....	+416	−721
214g....	−352	−768	302a.....	+162	−286	386c.....	+472	+52
218a....	−278	−515	302b.....	+164	−270	386e.....	+531	−56
218b....	−320	−595	302c.....	+224	−264	410a.....	+577	−247

scale errors, is ±0.125 magnitude; the corresponding photo-visual result is ±0.087. From this it follows that the accordance of the separate photo-visual scales must be even better than that of the results in Table XII. A discussion of the residuals proves this to be the case.

IX. COMPARISONS WITH OTHER MAGNITUDES

The reference of the Mount Wilson photographic magnitudes to the international zero point introduces a large systematic difference into the comparison with *H.C.*, No. 170. Between the tenth and

TABLE XI

SYSTEMATIC DIFFERENCES FOR VARIOUS APERTURES (UNIT=0.01 MAG.)

MEAN MAG.	*G*	*g*	32	14	8, 6	*S*	MEANS	
							Screens	Diaphragms
11.4......	+9.6	+8.4	−1.3	−1.6	−2.8	+11.1	+9.4	−1.6
12.7......	−0.6	+2.6	−0.8	+1.3	−0.8	+ 5.0	+0.3	−0.8
13.7......	−2.2	+6.2	−0.2	+0.7	−2.5	+ 0.9	+0.7	−1.2
14.2......	−2.4	+4.8	+0.6	+0.8	−0.3	− 6.4	−0.8	+0.6
14.8......	−5.3	−0.4	+0.7	+0.7	+1.9	− 5.9	−4.3	+0.8
15.2......	−5.2	−1.7	−0.2	+0.9	+3.0	− 4.8	−4.5	+0.6
15.5......	−7.5	−1.5	−0.8	+2.1	+2.5	− 8.5	−6.2	+0.7
16.4......	−8.2	−0.2	−0.4	+1.9	+5.1	−16.2	−5.4	+1.4
17.1......	−7.3	−0.2	+1.9	−0.4	+2.8	....	−4.5	+1.1
No. scales.	5	2	17	10	5	3	7	32
No. values.	423	156	2326	1654	507	227	579	4487

the sixteenth magnitudes this is nearly constant. Below this region there is a divergence which rapidly increases and, for the faintest stars given, amounts to about one magnitude. The faintest magnitude given in *H.C.*, No. 170, is 21.00; the faintest here shown is about 20.

Although some modification of the scale of *H.C.*, No. 170, has been made by Miss Leavitt in her final discussion of the data,[1] the changes are not great. They affect the divergence for the bright stars only slightly, and that for the faint ones not at all. A detailed comparison with the Harvard scale is reserved for a later paper, but it may be remarked here that the divergence at the lower end of

[1] *Harvard Annals*, **71**, Part III, 1914.

the scale is to be attributed to differences in the methods of reduction. The explanation of that for the bright stars is less obvious,

TABLE XII

SYSTEMATIC DEVIATIONS OF LONG-EXPOSURE PLATES (UNIT=0.01 MAG.)

Mean Mag.	769	788	795	808	196	200	204	230	232	235
11.1	+21	−26	−11	−24	− 4	+11	+15	+ 4	− 9	+26
12.2	+ 2	−22	−17	− 6	−23	+ 6	+10	− 4	0	+15
13.2	+ 4	− 1	−10	+ 7	− 5	− 2	− 7	+ 2	− 1	+11
13.7	− 7	+ 4	0	+10	−18	+ 4	−13	−11	+ 4	+12
14.1	− 4	0	+ 1	+ 2	+ 6	+ 3	+ 3	−11	+ 4	− 2
14.6	+ 1	+ 6	+ 1	− 6	− 2	+ 5	− 7	− 3	+ 4	−12
15.1	− 2	+ 7	+ 2	+ 4	+ 7	− 2	+ 9	+ 4	+ 2	− 9
15.6	+ 2	−12	+ 1	+16	+10	− 2	− 3	+ 3	+ 1	+ 9
16.1	+ 5	−12	0	+ 7	+14	+ 7	− 1	+ 6	− 4	0
16.6	+15	− 6	+ 2	+ 6	− 1	+12	− 7	− 2	−11	− 7
17.1	+19	+ 5	+ 4	− 7	− 5	+ 8	−14	− 6	−19	− 4
17.6	+15	− 4	+ 7	− 3	−11	+ 9	−12	− 4	−12	0
18.1	+ 8	−12	+ 9	0	− 2	+ 2	+ 2	− 6	−18	+ 5
18.6	+25	+27	......	......	+ 6	−10	+16	− 7	−10	+13
19.1	......	......	......	......	+22	−13	......	− 4	− 7	+18
19.6	......	......	......	......	......	−30	......	......	......	......
A.D.	14.7	15.6	10.6	15.0	14.6	12.7	16.0	11.0	13.5	12.3
No.	181	168	179	154	168	300	170	309	292	294
Ap.	32	32	32	14	6	6	6	14	14	14

Mean Mag.	310	312	313	314	225	229	1343	1347	1550	1561
11.1	+ 2	− 4	−19	+26	......	+10	+ 3	......	......	......
12.2	+ 1	+15	− 5	+16	......	− 1	−12	−12	......	......
13.2	− 3	+ 6	+ 2	+ 5	......	− 1	− 2	+ 2	......	......
13.7	−10	+11	+ 2	− 7	......	− 6	+ 9	+ 5	......	......
14.1	0	− 4	+ 3	−11	......	− 2	− 6	− 9	......	......
14.6	− 1	+ 7	+11	− 8	− 7	− 1	+ 6	− 8	......	......
15.1	+ 5	− 6	+ 2	−15	− 5	+ 1	+ 2	+ 2	......	+13
15.6	+ 4	− 5	−13	−13	+ 4	+ 9	+ 1	+ 4	+ 4	−14
16.1	− 1	+ 4	− 3	−14	+ 8	+ 4	− 2	− 1	− 2	+ 3
16.6	+ 3	+ 8	− 1	− 7	+ 2	− 5	0	+ 5	......	−22
17.1	+ 5	+ 8	+ 5	+ 5	− 2	− 1	− 1	+ 3	0	−10
17.6	+ 2	+ 4	+11	+ 9	− 5	+ 2	− 1	− 4	+15	− 7
18.1	+ 8	+ 4	+ 9	+ 9	− 4	− 1	− 6	− 7	+ 9	− 2
18.6	+14	+ 1	+ 4	+15	− 3	− 5	− 7	−10	+ 2	− 4
19.1	+12	0	− 1	+10	−17	−14	+25	+ 2	+16	0
19.6	......	......	......	......	−14	......	......	+32	+28	+ 8
A.D.	13.3	13.5	12.3	14.1	12.7	10.7	11.2	11.9	14.8	12:1
No.	277	307	281	333	323	354	253	267	181	179
Ap.	14	14	14	32	60	60	60	60	60	60

although some information is afforded by a re-reduction of the Harvard plates by methods which could not well be employed in the initial discussion of the data.

Since the zero points for the results by Chapman and Melotte and by Dziewulski depend upon the magnitudes of *H.C.*, No. 170, they, too, show large systematic differences when compared with the final Mount Wilson scale. Here again the differences are nearly constant, so that for the region in question the four scales are sensibly parallel; but the agreement becomes even better when it is noted that each of the three series of differences is affected by a more or less pronounced color equation.

By plotting the differences MW−HC, MW−Gr, and MW−Dz against color indices, the following relations were found:

$$\begin{aligned} \mathrm{MW}-\mathrm{HC} &= +0.30+0.15\,C \\ \mathrm{MW}-\mathrm{Gr} &= +0.23+0.27\,C \\ \mathrm{MW}-\mathrm{Dz} &= +0.31-0.06\,C \end{aligned}$$

in which C represents the color index.

The first of these, which is derived from the values of MW−HC for magnitudes 10–15, is a mean result and does not necessarily apply to any given star. The magnitudes of *H.C.*, No. 170, are based upon data obtained with many different instruments, among them the 60-inch reflector at Mount Wilson, and the results enter in varying proportions into the final magnitudes. Although reductions to a standard system were made in the case of stars known to be red, the HC results are not altogether homogeneous, for the colors of the fainter stars, many of which are also red, were not then known. In consequence, each star requires a special correction for color. Moreover, the corrections decrease in amount with increasing magnitude, for with the fainter objects the influence of the Mount Wilson observations entering into the HC results becomes increasingly predominant. The detailed determination of these corrections which reduce the differences to the system of the reflector will be given later. The results, however, appear in Table IX under the heading MW−$\mathrm{HH_w}$.[1]

[1] The symbol $\mathrm{HH_w}$ designates the magnitude system of *H.C.*, No. 170, after the application of the following corrections: (*a*) corrections to complete the reduction to the standard color system adopted by Miss Leavitt; (*b*) a zero-point correction of +0.08 mag. applied in her final discussion in *H.A.*, **71**, Part III; (*c*) a color correction which refers the results to the color system of the Mount Wilson reflector. The addition of (*a*) and (*b*) to the results of *H.C.*, No. 170, gives what may be called the Harvard Homogeneous Scale (HH). The further application of (*c*) gives the system $\mathrm{HH_w}$. Details of this part of the discussion will appear in *Mt. Wilson Contr.*, No. 98.

The corrected differences for Gr and Dz are similarly shown under the headings $MW-Gr_1$ and $MW-Dz_1$. For these the color equations given above, including the constant term, have been used as they stand.

With the exception of the beginning and ending of the $MW-HH_w$ series, the residuals are very satisfactory, at least for all cases including any considerable number of observations. The parallelism of all four scales is now very good between the ninth and the sixteenth magnitudes.

TABLE XIII

COMPARISON OF SCALES FOR BRIGHT STARS

Star No.	Photographic				Photo-visual			
	MW	MW−G	MW−Y	MW−HH$_w$	MW	MW−P	MW−Y	MW−HC
1*s*....	2.54	....	(−31)	−25	2.08	− 4	−12	− 4
1.....	4.39	− 1	− 8	−16	4.37	−13	−13	− 7
2.....	5.30	+10	+ 7	− 1	5.28	+10	− 5	−10
3.....	5.83	+ 7	+ 8	− 1	5.56	− 7	− 7	− 6
4.....	5.91	− 7	−12	− 8	5.84	− 7	+ 2	− 2
5.....	6.45	− 5	− 6	− 2	6.47	− 4	− 7	+ 4
2*s*....	6.45	0	0	− 2	6.33	+ 2	+17	+ 5
1*r*....	6.61	−11	−16	−26	5.09	+10	+ 5	−17
3*s*....	6.64	− 1	+ 2	− 1	6.35	+ 6	+14	+ 2
6.....	7.11	− 9	− 5	+ 4	7.05	− 4	0	+ 4
7.....	7.41	+ 7	+11	+16	7.52	+ 1	− 2	+ 8
2*r*....	7.94	+ 9	−13	+ 3	6.35	+ 7	+ 3	−20
Z.P. correction .		+ 6	+47			−19	+ 9	

Since the zero-point reduction for the Mount Wilson photo-visual magnitudes is only 0.03, the differences in the last column of Table VIII show with sufficient exactness the relation of the final values to the visual magnitudes of *H.C.*, No. 170. As already remarked, there is here also an appreciable color equation, the agreement for the red stars being noticeably better than for the white.

There remains still to be noted a comparison of the Mount Wilson results with those of Parkhurst, Müller and Kempf, and Schwarzschild. The differences are shown in Table XIII alongside the corresponding values of $MW-HH_w$. To facilitate the comparison, the Göttingen, Yerkes, and Potsdam magnitudes have received the zero-point corrections which appear at the bottom of the table.

In addition, the Yerkes photographic magnitudes have been multiplied by 0.94.[1] There is some evidence that the Yerkes photo-visual magnitudes require a similar correction, but as the case is not altogether clear, no change has been made in the slope of the scale.

X. COLOR OF THE STARS

One of the most interesting results of the investigation is the series of color indices given in Table IX. Attention has already been called to the gradual change in the minimum color index with increasing magnitude.[2] The additional data now available only confirm in all essential particulars the results previously found. At the seventeenth magnitude (photo-visual) the smallest color index appears to be 0.7 or 0.8 mag. The change with increasing magnitude is approximately linear.

SUMMARY

The paper deals with the determination of absolute scales of photographic and photo-visual magnitude within the intervals 2.5–20.0 and 2.0–17.5, respectively. With diaphragms and screens scales were first established for the stars of intermediate brightness. These were then extended in both directions to include both bright and faint stars. The results give photographic and photo-visual magnitudes for 617 and 339 objects, respectively, of which 311 appear in both groups. For these color indices are therefore available. The relation between color index and magnitude previously announced is confirmed.

The internal accordance of the results is satisfactory. With due allowance for color, the photographic scale agrees well from the ninth to the sixteenth magnitude with results found at Harvard, Greenwich, and Potsdam. It also agrees well with the Yerkes and Göttingen magnitudes of bright stars, for which values between 4.4 and 7.9 are available. The divergence from the scale of *H.C.*, No. 170, below the sixteenth magnitude is due to differences of reduction. That for the bright stars has been decreased by the

[1] *Vierteljahrsschrift der Astron. Gesellschaft*, **47**, 356, 1913.

[2] *Mt. Wilson Contr.*, No. 81; *Astrophysical Journal*, **39**, 361, 1914.

correction for color, but there are still important differences which will be considered in *Mt. Wilson Contr.*, No. 98.

The photo-visual scale agrees well with other determinations in the region of the bright stars, and coincides with the visual scale of *H.C.*, No. 170, at the twelfth magnitude. For intermediate points, the comparison with the latter scale is less satisfactory and shows the influence of color.

Mount Wilson Solar Observatory
January 16, 1915

PARALLAXES OF FOUR VISUAL BINARIES

By FREDERICK SLOCUM

The parallaxes of the following binaries have been determined from photographs made with the 40-inch refractor of the Yerkes Observatory. The methods of exposure, measurement, and reduction have been explained in this *Journal* by F. Schlesinger in Vols. **32**, **33**, and **34**, and by F. Slocum and S. A. Mitchell in **38**, 1, 1913.

42 α Comae Berenices ($13^h 5^m, +18°3'$)

This is a short-period binary, 25.3 years, with a large proper motion, 0".49 per year. The plane of the orbit is nearly in the line of sight so that the position angle is practically constant at about 190°, the two stars almost, if not actually, making an occultation at intervals of about 13 years. The components are of equal magnitude, 5.2, and the distance is always less than 1".0.

TABLE 1

PLATES OF 42 α COMAE BERENICES

No.	Date	Hour Angle	Observers	Quality of Images
1094	1913 Feb. 1	$-1^h.1$	Su, Sl	Fair
1107	Feb. 6	−1.1	Su, M	Fair
1117	Feb. 8	−0.6	Sl	Good
1127	Feb. 9	−0.3	Su, M	Fair
1225	May 18	+0.4	Sl	Good
1230	May 31	+1.3	Su, M	Poor
1236	June 1	+0.6	Su, Sl	Poor
1499	1914 Feb. 15	−0.3	Su, Sl	Fair
1500	Feb. 15	+0.3	Su, Sl	Fair
1505	Feb. 26	+0.5	Su, Sl	Good
1588	May 17	+0.3	Su, Sl	Fair
1590	May 24	+0.5	Su, Sl	Good
1593	May 30	+0.2	Su, Sl	Good

Sl = Slocum, Su = Sullivan, M = Mitchell, V = Van Maanen, L = Lee.

During the period covered by my plates, 1913–1914, the distance was so small that the stars could not be separated on the plates and the measures were made upon the center of the system.

The tables give the data for the plates and their reductions. Unless otherwise noted, values are in terms of scale-divisions. 1 division = 2″.66.

COMPARISON STARS

No.	Diameter	X (Right Ascension)	Y (Declination)	Dependence
	mm			
1	0.23	−279	+257	+0.061
2	.11	−257	+ 56	+ .197
3	.35	−210	−123	+ .310
4	.16	+159	−205	+ .268
5	.14	+250	− 11	+ .107
6	.16	+337	+ 26	+0.057
Parallax star	0.26	− 43.9	− 66.2	....

The mean magnitude of the comparison stars is about 10.7.

TABLE 2

REDUCTIONS FOR 42 α COMAE BERENICES

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
1094	+0.464	0.7	+0.825	−226	−0.013	−0″.03
1107	.468	0.7	+ .788	−221	− .006	− .01
1117	.477	0.7	+ .772	−219	+ .004	+ .01
1127	.490	0.7	+ .763	−218	+ .018	+ .04
1225	.393	0.7	− .598	−120	− .007	− .02
1230	.406	0.4	− .741	−107	+ .015	+ .03
1236	.384	0.4	− .750	−106	− .006	− .01
1499	.308	0.7	+ .710	+153	.000	.00
1500	.316	0.7	+ .709	+153	+ .008	+ .02
1505	.294	1.0	+ .587	+164	− .007	− .02
1588	.248	0.7	− .582	+244	+ .008	+ .02
1590	.231	1.0	− .665	+251	− .004	− .01
1593	+0.232	1.0	−0.728	+257	+0.001	0.00

The normal equations are:

$$\begin{aligned} 9.4\,c + 2.6900\,\mu + 0.9685\,\pi &= +3.2878 \\ +38.6329\,\mu - 5.7863\,\pi &= -0.8536 \\ +4.6894\,\pi &= +0.7045 \end{aligned}$$

from which

$$c = +0.3601$$
$$\mu = -0.0439 = -0''.117$$
$$\pi = +0.0217 = +0''.058 \pm 0''.008$$

Probable error corresponding to unit weight, $\pm 0.0055 = \pm 0''.015$.

2 η Coronae Borealis ($15^h 19^m, +30°39'$)

This system has already described more than two revolutions, so that the period is very accurately known. According to Lohse it is 41.6 years. The components are of 5.6 and 6.1 magnitudes, and their distance varies from about 0''.04 to nearly 1''.0. They are not separated on the plates, and settings were made on the center of the composite image.

TABLE 1

PLATES OF 2 η CORONAE BOREALIS

No.	Date	Hour Angle	Observers	Quality of Images
698	1912 Mar. 17	$-0^h.6$	Sl,	Good
711	Mar. 21	-0.8	Su, Sl	Poor
786	June 15	-0.3	Su, M	Fair
789	June 22	$-.01$	Su, M	Good
1111	1913 Feb. 6	$+.01$	Su, M	Poor
1120	Feb. 8	$-.03$	Su, Sl	Good
1121	Feb. 8	$+0.3$	Su, Sl	Fair
1130	Feb. 9	$+0.2$	Su, M	Fair
1139	Feb. 12	-1.0	Su, Sl	Poor
1143	Feb. 16	-0.2	Su, M	Good
1257	June 12	-0.1	Su, Sl	Fair
1262	June 21	0.0	Su, M	Poor
1268	June 22	$+0.2$	Su, Sl	Fair
1289	July 3	$+0.1$	Su, Su	Fair

COMPARISON STARS

No.	Diameter	X (Right Ascension)	Y (Declination)	Dependence
	mm			
1	0.11	-300	-219	$+0.221$
2	.18	-150	$+162$	$+.247$
3	.12	$+196$	-211	$+.254$
4	.19	$+254$	$+268$	$+0.278$
Parallax star	0.32	$+16.9$	$+12.3$	....

The mean magnitude of the comparison stars is about 12.0.

TABLE 2

REDUCTIONS FOR 2 η CORONAE BOREALIS

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
698	−0.147	0.7	+0.787	−287	+0.013	+0″.03
711	.114	0.4	+ .748	−283	+ .047	+ .08
786	.180	0.7	− .525	−197	− .002	− .01
789	.203	1.0	− .618	−190	− .024	− .06
1111	.103	0.4	+ .951	+ 39	− .015	− .03
1120	.097	1.0	+ .953	+ 41	− .010	− .03
1121	.114	0.7	+ .953	+ 41	− .027	− .06
1130	.083	0.7	+ .954	+ 42	+ .004	+ .01
1139	.082	0.4	+ .954	+ 45	+ .004	+ .01
1143	.079	1.0	+ .950	+ 49	+ .007	+ .02
1257	.106	0.7	− .479	+165	− .005	− .01
1262	.058	0.4	− .602	+174	+ .044	+ .07
1268	.107	0.7	− .615	+175	− .005	− .01
1289	−0.088	0.7	−0.744	+186	+0.016	+0.03

The normal equations are:

$$
\begin{aligned}
9.5\,c - 0.2250\,\mu + 2.3371\,\pi &= -1.0993\\
+23.7695\,\mu - 1.4937\,\pi &= +0.4834\\
+5.9994\,\pi &= -0.1515
\end{aligned}
$$

from which

$$
\begin{aligned}
c &= -0.1220\\
\mu &= +0.0209 = +0''.056\\
\pi &= +0.0275 = \mathbf{+0''.073 \pm 0''.014}
\end{aligned}
$$

Probable error corresponding to unit weight, $\pm 0.0117 = \pm 0''.031$.

70 Ophiuchi ($18^{h}0^{m}+2°31'$)

This system has a very large proper motion, 1″.13 per year. It has recently completed one revolution since the date of discovery, its period being 87.9 years. The components are of 4.3 and 6.0 magnitudes and vary from about 1″.5 to 6″.5 in distance. They are clearly separated on the plates, but the companion is so much reduced by the occulting disk that on many of the plates its image is too weak for accurate measurement. The accompanying data, therefore, apply to the brighter star only.

TABLE 1

PLATES OF 70 OPHIUCHI

No.	Date	Hour Angle	Observers	Quality of Images
247	1910 Apr. 10	$-1^h.1$	Su, Sl	Poor
410	1911 Apr. 22	−0.6	Su, Sl	Good
468	Aug. 19	+1.0	Su, Sl	Poor
880	1912 Sept. 7	+1.0	Su, M	Fair
1335	1913 Aug. 2	+0.6	Su, M	Good
1340	Aug. 16	+1.0	Su, Su	Poor
1341	Aug. 17	+0.2	Su, Su	Fair
1555	1914 Apr. 9	−0.4	Sl, L	Fair
1572	Apr. 25	−0.6	Su, L	Fair

COMPARISON STARS

No.	Diameter	X (Right Ascension)	Y (Declination)	Dependence
	mm			
1	0.18	−344	−198	+0.169
2	.19	−299	+255	+ .155
3	.16	0	−194	+ .173
4	.14	+ 20	+190	+ .161
5	.18	+263	−245	+ .178
6	.31	+360	+192	+0.164
Parallax star	0.26	+ 4.6	− 9.2	....

The mean magnitude of the comparison stars is about 10.5.

TABLE 2

REDUCTIONS FOR 70 OPHIUCHI

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
247	−0.027	0.4	+0.940	−928	−0.010	−0″.02
410	.021	1.0	+ .854	−551	+ .004	+ .01
468	.148	0.4	− .836	−432	+ .012	+ .02
880	.177	0.7	− .972	− 47	− .005	− .01
1335	.153	1.0	− .652	+282	− .006	− .02
1340	.152	0.4	− .812	+296	+ .008	+ .01
1341	.161	0.7	− .822	+297	.000	.00
1555	.032	0.7	+ .945	+532	− .011	− .03
1572	−0.017	0.7	+0.824	+548	+0.013	+0.03

The normal equations are:

$$
\begin{aligned}
6.0\,c+\quad 2.3640\,\mu-0.0987\,\pi&=-0.5757\\
+130.8917\,\mu\,\dot{-}\,4.2594\,\pi&=-0.6006\\
+4.2859\,\pi&=+0.3526
\end{aligned}
$$

from which

$$
\begin{aligned}
c&=-0.0945\\
\mu&=-0.0003\;=-0''.001\\
\pi&=+0.0798=+0''.212\pm0''.007
\end{aligned}
$$

Probable error corresponding to unit weight, $\pm 0.0055 = \pm 0''.015$.

The m's in the foregoing table have been corrected for orbital motion by the data given in Boss's *Preliminary General Catalogue*, p. 275.

A reduction using the uncorrected values of m yielded

$$\pi = +0''.209 \pm 0''.008$$

85 Pegasi ($23^h 56^m$, $+26°34'$)

According to Burnham this is "one of the most important and most interesting of the known binary systems. The shortness

TABLE 1

PLATES OF 85 PEGASI

No.	Date	Hour Angle	Observers	Quality of Images
584	1911 Dec. 15	$-0^h.1$	Sl, V	Good
588	Dec. 18	-0.2	Sl, V	Good
826	1912 July 21	-0.2	Su, M	Fair
847	Aug. 4	-0.2	Su, M	Poor
976	Nov. 2	-0.1	Su, Sl	Good
989	Nov. 10	-0.2	Su, Sl	Fair
999	Nov. 16	$+0.3$	M, Su	Good
1013	Nov. 24	-0.1	Su, Sl	Poor
1017	Nov. 28	$+0.2$	Su, Sl	Good
1050	Dec. 28	$+0.1$	Sl, Sl	Fair
1321	1913 July 20	-0.3	M, Su	Poor
1323	July 24	-0.8	Su, M	Good
1324	July 24	-0.2	Su, M	Good
1328	July 26	-1.0	Su, M	Good

COMPARISON STARS

No.	Diameter	X (Right Ascension)	Y (Declination)	Dependence
	mm			
2	0.16	−341	+274	+0.116
3	.21	+ 3	−257	+ .091
4	.21	+153	+210	+ .519
5	.16	+185	−227	+0.274
Parallax star	0.22	+ 90.9	+ 55.0	....

The mean magnitude of the comparison stars is about 10.9.

of its period, the rapid movement in space of both components, the relative nearness of this system to our own, and the extreme inequality in magnitude, and closeness of the stars, all combine to give this a leading place among the binary stars."

The proper motion is 1″.3 per year, and the period 25.4 years.

The components are of magnitudes 5.8 and 11.0 and are always less than 1″.0 apart.

The brighter component only appears on the plates.

TABLE 2

REDUCTIONS FOR 85 PEGASI

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
584	−0.066	1.0	−0.897	−348	−0.006	−0″.01
588	− .066	1.0	− .901	−345	− .008	− .02
826	+ .164	0.7	+ .808	−129	− .003	− .01
847	+ .198	0.4	+ .678	−115	+ .024	+ .04
976	+ .212	1.0	− .597	− 25	+ .008	+ .02
989	+ .227	0.7	− .685	− 17	+ .019	+ .04
999	+ .222	1.0	− .743	− 11	+ .011	+ .03
1013	+ .214	0.4	− .807	− 3	− .001	.00
1017	+ .220	1.0	− .834	+ 1	+ .002	+ .01
1050	+ .215	0.7	− .894	+ 31	− .024	− .05
1321	+ .442	0.4	+ .818	+235	− .013	− .02
1323	+ .448	1.0	+ .786	+239	− .009	− .02
1324	+ .462	1.0	+ .786	+239	+ .005	+ .01
1328	+0.456	1.0	+0.769	+241	−0.002	−0.01

The normal equations are:

$$
\begin{aligned}
11.3\,c - 0.4270\,\mu - 1.8951\,\pi &= +2.6538\\
+45.3106\,\mu + 11.6876\,\pi &= +3.8494\\
+7.1043\,\pi &= +0.6882
\end{aligned}
$$

from which

$$
\begin{aligned}
c &= +0.2431\\
\mu &= +0.0791 = +0''.210\\
\pi &= +0.0316 = +0''.084 \pm 0''.010
\end{aligned}
$$

Probable error corresponding to unit weight, $\pm 0.0075 = \pm 0''.020$.

SUMMARY OF RESULTS

Star	*B.D.* Number	Spectrum	Proper Motion	Relative Parallax	Probable Error	Number of Plates	Probable Error of One Plate	Number of Comp. Stars
42 Comae ..	+18°2697	F5	0''.49	**+0''.058**	+0''.008	13	±0''.015	6
η Coronae .	+30.2653	G	0.23	**+ .073**	.014	14	.031	4
70 Ophiuchi	+ 2.3482	K	1.13	**+ .212**	.007	9	.015	6
85 Pegasi...	+26.4734	G	1.30	**+0.084**	±0.010	14	±0.020	4

From the foregoing may be obtained the absolute parallax, cross-velocity, motion in space, mass, and luminosity of each system, together with the elements of the orbits, the radial velocities, and the magnitudes, as shown in Tables A and B.

TABLE A

	Galactic Latitude	Mean Mag. of Comp. Stars	Mean Parallax of Comp. Stars	Absolute Parallax of Binaries	Period (*P*)	Semi-Major Axis (*a*)	Cross-Velocity
42 Comae	+79°.6	10.7	+0''.004	**+0''.062**	25.3y	0''.67	37.5 km
η Coronae	+56.4	12.0	.003	**.076**	41.6	0.89	14.3
70 Ophiuchi	+11.6	10.5	.004	**.216**	87.9	4.56	24.8
85 Pegasi.......	−35.0	10.9	0.004	**+0.088**	25.4	0.81	70.0

TABLE B

	Radial Velocity	Magnitudes A	Magnitudes B	Mass of System ☉=1	Motion in Space Relative to ☉	Luminosity ☉=1 A	Luminosity ☉=1 B
42 Comae	−20.8 km	5.2	5.2	**1.97**	43 km	2.3	2.3
η Coronae....	− 9.7	5.6	6.1	**0.94**	17	1.1	0.7
70 Ophiuchi....	− 7.4	4.3	6.0	**1.22**	26	0.4	0.1
85 Pegasi......	−31	5.8	11.0	**1.21**	77	0.7	0.006

The mean parallaxes of the comparison stars are taken from Kapteyn's table in *Groningen Publications*, No. 24. The absolute parallaxes of the binaries are simply their relative parallaxes plus the weighted mean parallaxes of the comparison stars.

The masses, in terms of the mass of the sun, were computed from the formula

$$M = \frac{a^3}{\pi^3 P^2} ,$$

where a is the angular semi-major axis, π the absolute parallax, and P the period in years.

The "absolute magnitude" of a star, as defined by Kapteyn, is the magnitude it would appear to have if placed at such a distance that its parallax would be one-tenth of a second of arc. This is expressed in terms of the observed magnitude m by the equation

$$M = m + 5 + 5 \log \pi .$$

If the sun's apparent stellar magnitude is taken as -26.5, its absolute magnitude on this scale would be 5.1, and the relative brightness of a star and the sun if placed at the same distance, or the luminosity of the star in terms of the sun, may be obtained from the formula

$$\log l_s = -\frac{4}{10}(M_s - 5.1),$$

in which l_s and M_s represent the luminosity and absolute magnitude of the star.

For the first two stars there are no data for determining the relative masses of the components. If we assume them to be equal, in the case of 42 Comae, each is 0.98 of the mass of the sun and 2.3 times as bright. The components of η Coronae are of the order of half the mass of our sun, while A is a trifle brighter and B somewhat fainter than the sun.

The following values of the mass-ratio of the components of 70 Ophiuchi have been published:

$\frac{B}{A}$	
4.0	(Prey)
1.0	(Comstock)
0.5	(Lau)
0.82	(Boss)

These are so discordant that little reliance can be placed upon the individual masses. If, however, we use the mean, 1.6, for the ratio of masses in connection with the mass of the system 1.22⊙, obtained above, we get the mass of A=0.47⊙ and B=0.75⊙, whereas A is four times as bright as B, and each is fainter than the sun, their luminosities being A=0.4⊙ and B=0.1⊙.

For 85 Pegasi the following ratios of masses have been obtained:

$\frac{B}{A}$
1.6 (Comstock)
4.0 (Furner)
3.0 (Lewis)
4.5 (Bowyer and Furner)
2.7 (Bowyer and Furner)
1.0 (Boss)

Here again there is great discrepancy, but it is to be noted that all computers make B, the fainter component, more massive than A. The mean is B=2.8 A in mass, while A is nearly 100 times as bright as B. Using the foregoing ratio and 1.21⊙ for the mass of the system, A=0.3⊙ and B=0.9⊙ in mass, whereas in luminosity A=0.7⊙ and B=0.006⊙.

The cross-velocities are expressed in terms of kilometers per second, and are obtained by the formula

$$V_c=4.74\frac{\mu}{\pi},$$

where μ is the annual proper motion and π the parallax.

The radial velocities are to be considered only as approximations. Definitive results have not been published for any of these stars. Of the values given, that for 42 Comae is from unpublished results obtained by Lee at the Yerkes Observatory; for η Coronae, Lee, *Astrophysical Journal*, **32,** 304, 1910; for 70 Ophiuchi, Campbell, *ibid.*, **29,** 227, 1909; for 85 Pegasi, Frost, *ibid.*, **25,** 63, 1907.

The motion in space is obtained simply by combining the radial and cross components.

Middletown, Conn.
February 26, 1915

Minor Contributions and Notes

THE RADIAL VELOCITIES OF STARS OF CLASS Md

The radial velocities of 24 long-period variable stars of class Md have been determined with a one-prism spectrograph[1] attached to the 37½-inch reflector of the Detroit Observatory. The fact

TABLE I

Star	Harvard Class Md.	Epoch of Obs. 1914	Obs. Radial Velocity: Bright Lines	Obs. Radial Velocity: Dark Lines	No. of Plates	Residual Velocity* Bright Lines
001755 T Cassiopeiae	8	Nov.	− 27 km	....	1	− 20 km
012502 R Piscium	7	Nov.	− 58	....	2	− 64
021024 R Arietis	4	Sept.	+101	....	3	+ 96
021403 o Ceti	9	Dec.	+ 53	....	2	....
			(+ 48)†	(+63)	......	+ 38
094211 R Leonis	10	Feb.	+ 1	+30	7−2	− 7
103769 R Urs. Maj.	8	May	+ 25	....	1	+ 32
123160 T Urs. Maj.	6	May	−107	....	3	− 98
132422 R Hydrae	0	May	− 23	....	1	− 21
134440 R Can. Ven.	9	June	− 21	....	2	− 9
142539 V Boötis	7	May	− 34	....	1	− 20
151731 S Cor. Bor.	9	Apr.	− 21	....	1	− 5
154615 R Serpentis	8	Apr.	+ 7	+33	3−1	+ 24
164715 S Herculis	6	Aug.	− 22	....	2	− 3
171401 Z Ophiuchi	0	June	− 92	....	3	− 74
180531 T Herculis	3	Sept.	−130	....	3	−110
181136 W Lyrae	0	July	−185	....	3	−165
183308 X Ophiuchi	8	Nov.	− 91	....	1	− 72
193311 RT Aquilae	9	July	− 54	....	3	− 36
194048 RT Cygni	5	Sept.	−127	....	4	−109
194632 χ Cygni	6	Nov.	− 17	....	2	....
			(− 21)†	(0)	......	− 3
205923 R Vulpeculae	6	June	− 17	....	3	− 2
210868 T Cephei	9	Nov.	− 30	....	2	− 17
231425 W Pegasi	8	July	− 35	....	3	− 28
235350 R Cassiopeiae	8	Sept.	+ 9	+35	6−2	+ 17

* On the assumption that the sun is approaching the point $\alpha = 270°0'$, $\delta = +28°0'$, with a speed of 20.0 km per second.

† The values in parentheses are by other observers: those for o Ceti by Campbell and Stebbins, *Lick Observatory Bulletins*, **2**, 78, 1903; those for χ Cygni by Eberhard, *Astrophysical Journal*, **18**, 198, 1903.

The dark-line velocities by the writer are preliminary and may be changed somewhat, but not materially, by the final reductions.

[1] *Publications of the Astronomical Observatory of the University of Michigan*, **1**, 37, 1912.

that the spectra contain strong bright lines makes it possible to observe faint stars photographically, with reasonable exposure times. The exposure for a star of this class, of magnitude 8.5, usually need not exceed two hours, provided the only requirement is good images of the stronger bright lines. Frequently, under these circumstances, the continuous spectrum is very weak or invisible.

The velocities, in most cases, depend on the bright hydrogen lines, particularly $H\gamma$ and $H\delta$. Nearly all the bright lines appear monochromatic, and hence are accurately measurable. The spectra will be further described, and details of the observations recorded, in the *Publications of the Detroit Observatory*.

In no instance does the velocity appear to be variable. However, practically all the observations were secured near the epoch of light-maximum. It is intended to extend the observations to other stars, and to study the spectra of certain stars more exhaustively, but it does not seem probable that many, if indeed any, of this group of stars will prove to be spectroscopic binaries.

The mean of the figures in the last column is −27 km. This may indicate that the radial velocity from the bright lines is systematically in error by that amount. Possibly that derived from the absorption lines is more nearly correct. The discrepancy between the velocities given by the bright and dark lines of stars of this class, discovered by Campbell in *o* Ceti[1], and by Eberhard in χ Cygni,[2] exists also in the cases of R Leonis, R Serpentis, and R Cassiopeiae. Table II contains all the instances known to the writer.

TABLE II

DIFFERENCE OF RADIAL VELOCITY FROM BRIGHT AND DARK LINES

Star	Bright − Dark	
o Ceti	−15 km	(Campbell)
R Leonis	−29	
R Serpentis	−26	
χ Cygni	−21	(Eberhard)
R Cassiopeiae	−26	
Mean	−23 km	

[1] *Lick Observatory Bulletins*, **2**, 78, 1903.

[2] *Astrophysical Journal*, **18**, 198, 1903.

The mean discrepancy between "Bright minus Dark," −23 km, agrees closely enough with the mean residual velocity, −27 km, to support the inference that the bright lines are displaced to the violet about 0.4 A by other causes than radial motion. However, the bright lines usually appear monochromatic, and one would not expect such a displacement, but might be more inclined to believe that they occupy their normal positions, save for Doppler effects, and that the absorption lines, presumably originating in a lower level of the star's atmosphere,[1] are displaced to the red by pressure. From the data at hand, this assumption would lead us to believe that, as a class, the Md stars are approaching the sun, which, again, seems unlikely. Observations in the southern skies would be useful in their bearing on this question.

The arithmetical mean of the residual velocities is 44 km. Applying the correction, +27 km to each velocity, to make the algebraic mean equal to zero, the arithmetical mean is 29 km. Combining this with radial velocities of other objects by Campbell,[2] we have the results given in Table III.

TABLE III

Spectral Types	No.	Average Radial Velocity
O and B	141	9.0 km
A	133	9.9
F	159	13.9
G and K	529	15.2
M	72	16.6
Md (Merrill)	24	29.
Planetary Nebulae	42	46.1

The writer would be glad to learn of any unpublished measures of the bright or dark lines of stars of class Md, which may be in existence at various observatories.

Paul W. Merrill

Ann Arbor, Mich.
January 1915

[1] Though this may well be doubted for the calcium lines.

[2] Taken from *Lick Observatory Bulletins*, **6**, 126, 1911, and from *Proceedings of the National Academy of Sciences*, **1**, 8, 1915.

REVIEWS

Color-Equation of Various Star Catalogues. By E. C. PICKERING. *Annals of Harvard College Observatory*, **76**, No. 2

Beitrag zur Frage nach der Abhängigkeit der Helligkeitsmessungen der Sterne von der Farbe. Von G. MÜLLER und P. KEMPF. Abdruck aus den *Astronomischen Nachrichten*, **199**, 89, 1914.

These two valuable contributions to the related problems of magnitude and color in stellar photometry may well be reviewed together. In the former, Professor Pickering has made a comparison of the *Revised Harvard Photometry* with 35 catalogues and parts of catalogues, in such a manner as to show the effect of color on the measures or estimates, and to provide tables for the reduction of the different catalogues to a common standard of color perception. The exceeding usefulness of such a work is evident, but is restricted by the limits of the comparison. The stars used are those of the first *Harvard Photometry* contained in Vol. **14** of the *Annals*, therefore mainly naked-eye stars, numbering not more than 3000 in the Northern Hemisphere. The catalogues compared begin with Hipparchus' and Sufi's stars of the Almagest and include, among others, the photometric catalogues of Seidel, Wolf, Oxford, and Potsdam; the estimates of Heis, Bailey, Herschel, and Argelander, and the various Harvard catalogues from Peirce to Vol. **46**; but excluding the later Vols. **70** and **74** which deal with fainter stars. We are thus for the first time in possession of data for applying the "color-equation" to most of the important catalogues of magnitude.

In Plate I, Fig. 7, it is shown graphically that the *Harvard Photometry* holds a middle position, in regard to color-equation, between the other catalogues; the extremes being Seidel's with an equation of +0.28, and Potsdam with −0.24. The author argues for the universal adoption of the Harvard system from the "fact that nearly all of the other observers agree with the Harvard color-equation within a tenth of a magnitude, and its use in various extensive researches now in progress." The force of this argument is, however, weakened by fact that the author has given as much weight to the estimates of Hipparchus and Sufi as to the *Potsdam Durchmusterung;* and as much to the estimates by Edmunds and by Howard as to Peirce's photometric catalogue. He seems also to have neglected the possible effect of the Purkinje phenomenon, which is considered at length in the second paper to be reviewed.

Müller and Kempf had previously compared the Harvard magnitudes contained in Vol. **14**, observed with the 2-inch meridian photometer, with those in Vol. **44**, observed with the 4-inch instrument, classified according to the estimates of color made at Potsdam. In a range between 2.5 and 6.5 in magnitude, and between white and yellow in color, the equation changed 0.28 magnitude in the direction expected from the Purkinje phenomenon. The appearance of the Harvard Vols. **70** and **74**, containing measures with the 12-inch photometer, led them to make a fresh comparison to see if the same effect was evident with the larger instrument. The results are shown in Table I.

TABLE I

COLOR	*Harvard Annals*, Vol. **70**			*Harvard Annals*, Vol. **74**		
	No. of Stars	12-Inch minus 4-Inch	*PD* minus 12-Inch	No. of Stars	12-Inch minus 4-Inch	*PD* minus 12-Inch
		M	M		M	M
W* to GW........	111	+0.14	+0.15	119	+0.13	+0.18
GW to GW+	164	+0.04	+0.16	169	+0.06	+0.16
WG− to WG+ ...	110	−0.13	+0.13	150	−0.07	+0.14
G−, etc..........	67	−0.17	+0.07	55	−0.16	+0.12
All...........	452	−0.01	+0.14	493	+0.01	+0.15

* W = white, GW = yellowish white, WG = whitish yellow, G = yellow.

The third and sixth columns of the table show the equation between the different apertures used at Harvard. The progression from the white to the yellow stars is well marked in each case and amounts to 0.31 magnitude and 0.29 magnitude, respectively, for the two volumes. The mean values are nearly zero, since the magnitudes from the 4-inch were used as the basis for the 12-inch. The fourth and seventh columns show the progression in the equation between the Harvard 12-inch and the Potsdam measures to be the same in direction but only one-quarter the amount (0.08 magnitude and 0.06 magnitude, respectively) of that between the two Harvard instruments.

The difference in color-perception between Harvard and Potsdam is thus mainly accounted for by the apertures used. The other possible cause suggested by Pickering, the tiring of the eye of the observers in the comparatively leisurely measures at Potsdam, would work in the wrong direction when the measures with the Harvard 12-inch are considered.

J. A. PARKHURST

YERKES OBSERVATORY
January 1915

Astronomy, a Popular Handbook. By HAROLD JACOBY. New York: The Macmillan Co., 1913. 8vo, pp. 435, figs. 124, plates 32. $2.50.

In this book Professor Jacoby follows rather a new plan, both in arrangement and in subject-matter. It is intended to attract the non-scientific reader, and at the same time to serve as a textbook. This is accomplished by introducing very little that is mathematical or technical in the main body of the book. Such material, designed for class use, is reserved for the appendix. A full index makes the book easy for reference.

The opening chapter gives a brief account of the various kinds of celestial objects that make up the universe, and their relations to one another. The chapter is calculated to awaken an interest for the more detailed discussions of the remainder of the book. One of the most commendable chapters is entitled "How to Know the Stars," a topic of much more interest to the general reader than descriptions of astronomical instruments, which subject is reserved for one of the later chapters, and even then little is given that is detailed. The discussions are supplemented by many illustrations and a number of excellent plates.

The work lacks scientific precision in places where more technical statements would add to its value. For instance, reference is made to the use of compound lenses in telescopes, to correct "certain optical imperfections," but no explanation is offered of the imperfections they are to eliminate or of the structure of the lens. A textbook on astronomy seems scarcely complete without such facts, and they could not detract from the interest of the reader possessing a fair understanding of popular scientific truths. There are many instances of redundancy in the style. The book is a step in the direction of popularizing astronomy, and the author's experience as a teacher has enabled him to appreciate points of difficulty and to present facts in an interesting manner.

JESSIE M. SHORT

PLATE VI

North

E. E. Barnard

NEBULOUS REGION NEAR AND WEST OF 38 OMICRON PERSEI

Center of Plate (1855.0) $\alpha = 3^h 29^m$, $\delta = +31^\circ 15'$

10 inch Bruce telescope of the Yerkes Observatory 1914 November 21, Exposure $6^h 41^m$

Scale $\begin{cases} 1 \text{ cm} = 0^\circ.56 \\ 1 \text{ in.} = 1^\circ.42 \end{cases}$

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A GREAT NEBULOUS REGION NEAR OMICRON PERSEI

By E. E. BARNARD

The study of the large diffused nebulae and the dark regions of the sky is quite impossible with the best visual telescopes. It would seem hopeless to learn much about them with the ordinary means of observation. These diffused nebulosities are very faint to the eye; the contracted field of the telescope allows only a very small portion of such objects to be seen when visible at all. Almost any telescope is too powerful for their successful observation—indeed the more powerful the telescope the more they are diffused and the smaller the portion that can be seen. Our knowledge of the existence of most of these objects would be very small if we depended on the visual telescope for their detection, and the most interesting of them would be entirely unknown.

These remarks apply with almost equal force to the vacant or starless regions of the sky, for though their existence in some cases might be known to the visual telescope (they are due mainly to the absence of very faint stars), their true forms and their relation to the diffused nebulae would, in almost every case, be unknown. It is due to photography, and especially to the work done with the ordinary "portrait lens," that they have become known and that their study has been made possible. The wide field and great

light-grasping power of the portrait lens, coupled with the very long exposures to which the sensitive plate can be subjected, give ideal conditions for the study of the widely diffused nebulosities and the large dark spaces. Attention has been called frequently in this journal and elsewhere to regions of this kind which are of special interest—where apparently an intimate connection exists between the vacancies and the large masses of nebulosity. It has been shown in these papers that there is evidence of the existence of some kind of dark or partly luminous matter between us and the fainter stars which, by obscuring the stars, produces the apparent vacancies, and that the diffused nebulosities, referred to above, are the visible evidence of this matter. Regions of this kind were found in Scorpio, in Ophiuchus, and in Taurus. In *Publications of the Lick Observatory*, **11**, Plate 16, I called attention to a condition like this near the star Omicron Persei in the lower right corner of that photograph. Some of the nebulosity is shown faintly, and it was suggested that a long exposure at that point would perhaps show more of this matter, its presence being indicated by the otherwise unexplained absence of the small stars.

On November 21, 1914, I gave an exposure of 6 hours and 41 minutes on this region with the Bruce 10-inch and 6-inch telescopes. A large, feebly luminous nebulosity with considerable detail in it is shown on these plates. The more obscure parts of this nebula are excessively faint, but the brighter details are well shown. The nebula fits into the vacancy referred to and seems (by obscuring their light) to account for the absence of the small stars. This photograph is reproduced here in Plate VI. It will be noticed, as in other cases to which I have called attention, that in the brighter part of the nebula west of Omicron Persei the background of small stars is continuous. It is only where the nebulosity is very feeble that the stars seem to be more or less missing.

The center of the brightest portion of the nebulosity is in α 3^h29^m, $\delta+31°40'$. In this, about 1° west of Omicron Persei, in α 3^h31^m, $\delta+31°40'$, is a black area nearly a degree in diameter, in which is a bright strip some 20′ long, lying northwest and southeast. In the feebler parts of the nebula, about 40′ south of the dark spot, is a very irregular dark structure.

The great nebulosity, including its feebler portions, extends roughly 7° or 8° east and west and about 3° north and south. Its brighter portion is some 2° in diameter, and consists of cloudlike structures with the dark opening referred to on the south. There are many dark forms in the feebler portions of the nebulosity, especially in the southwestern part. Apparently there is a rift or opening free from nebulosity in $\alpha\ 3^h26^m$, $\delta+31\frac{1}{2}°$, through which, seemingly, the background of stars is visible. This includes the stars B.D.+31°616 ($6^m.5$) and +31°619 ($7^m.0$). It is about $1\frac{1}{2}°$ long and $\frac{1}{2}°$ wide.

The nebulosity about B.D.+30°548 (N.G.C. 1333) is roundish and not symmetrical with respect to the star—its center seems to be several minutes to the south. Some faint stars are involved and a thin short strip of nebulosity lies close south of it. The following three nebulous stars are not in any of Dreyer's lists of nebulae. B.D.+30°540 ($8^m.8$) is in a faint and close nebulous atmosphere. B.D.+30°565 ($9^m.1$) is partly surrounded by an irregular, more or less curved nebulous mass. B.D.+31°597 ($7^m.0$) is very closely nebulous. A peculiarity of this nebulous condition is that, on the plate made with the 6-inch lens, its image, compared with that of B.D.+31°599 ($7^m.5$), is relatively much smaller than it is on that with the 10-inch, made at the same time. This is due to the greater scale of the 10-inch.

A nebulosity close south of Omicron Persei is mixed up with a number of small stars, several of which are very close together and appear to be the center of condensation. The principal star of these is B.D.+31°643, of magnitude 8.2 (see *Monthly Notices*, **60**, 261, 1900). It is 7′ south and 3′ following Omicron Persei. This nebulosity extends in a diffused manner beyond Omicron and has a winglike extension south from it for 10′ or 15′. It is very greatly brighter than any portion of the large nebulosity west of Omicron Persei. A small star (not in *B.D.*) 10′ west of Omicron seems to have a very small condensed nebula close west of it. All this region near the stars B.D.+29°565, +30°540 and N.G.C. 1333 is full of feeble nebulosity in which are many dark structures. Some of these are especially noticeable north of B.D. +29°565 and south of +30°540 and also south of N.G.C. 1333.

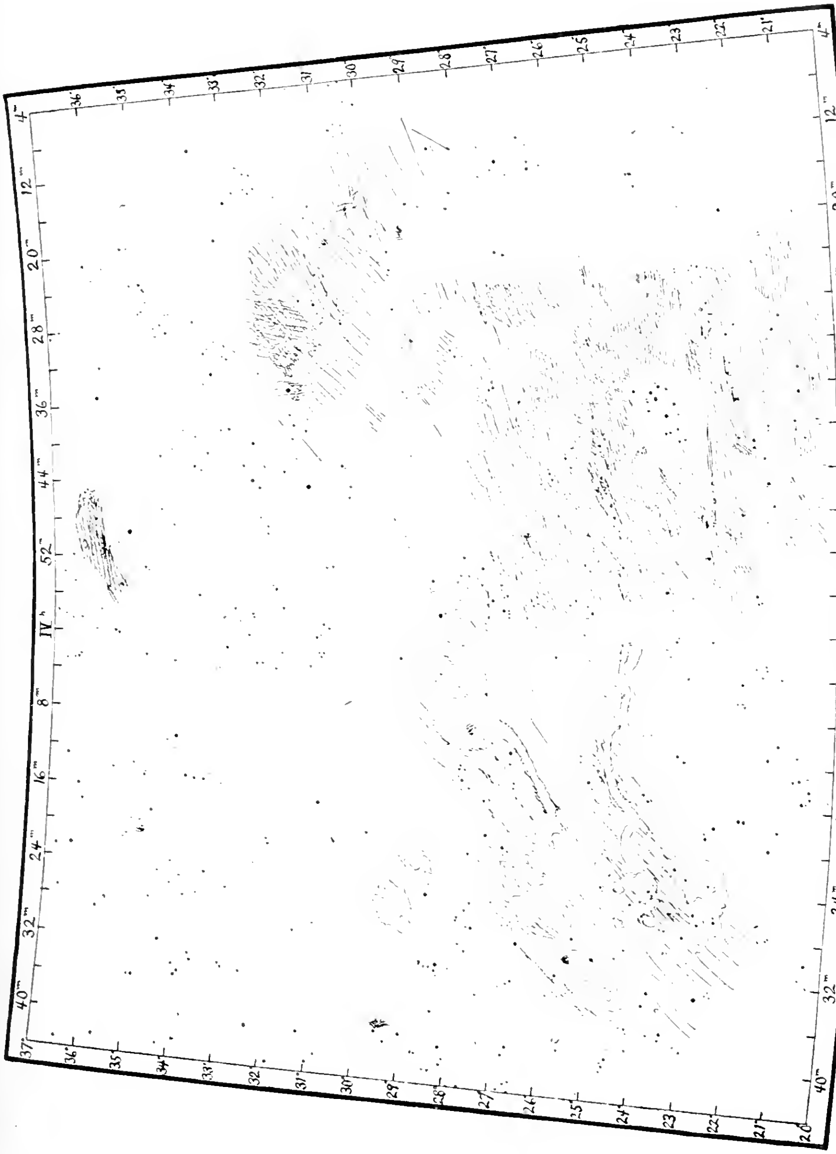
This great nebula and vacant space near Omicron Persei are but a part of a very remarkable region which includes the Pleiades and is roughly bounded by the following co-ordinates:

$$\alpha\ 3^h4^m \text{ to } \alpha\ 4^h40^m$$
$$\delta +20^\circ \text{ to } \delta +37^\circ$$

In this large region are comprised the present nebulous mass, the "Exterior Nebulosities of the Pleiades" (*Monthly Notices*, **60,** 261, 1900), and the "Nebulous Background in Taurus" (*Astrophysical Journal*, **25,** 218, 1907). To show the relation of these remarkable regions the map on p. 257 has been prepared. Perhaps a word in connection with this chart is required. It roughly shows the region of diffused nebulosity and dark lanes in Taurus, the exterior nebulosities of the Pleiades, and the present nebulous region in Perseus. At the top in the position $\alpha\ 3^h50^m$, $\delta+36^\circ$ is the nebula N.G.C. 1499. (See *Astrophysical Journal*, **2,** 350 and *Publications of the Lick Observatory*, **11,** Plate 16.)

It would need a skilful artist to delineate correctly all the streaky nebulosities that are shown on the original photographs, especially in the region of the Pleiades. I am able to indicate only roughly the general distribution of this matter and the relation of the various parts to each other. For a study of their details and peculiarities in general, I would refer to the *Astrophysical Journal*, **25,** 218, Plates XI and XII, "On a Nebulous Groundwork in the Constellation Taurus," and especially in the case of the Pleiades to *Publications of the Lick Observatory*, **11,** Plate 15, and to *Monthly Notices of the R.A.S.*, **60,** 258, Plates 9 and 10, the latter from a drawing by Mr. E. Calvert, a skilful artist. The title of this last paper is "Exterior Nebulosities of the Pleiades." In the present diagram the nebulosities about the Pleiades should also be shown extending farther to the west. I hope later to investigate that part of the sky more thoroughly and supply the missing nebulosities. I have not attempted to show the nebulosities that are involved in the Pleiades cluster itself.

I get the impression from several of the photographs that some of the luminous streaks to the east of the Pleiades ultimately become the dark lanes shown farther to the east. I hope to be able to confirm this later.



Map of the great Nebulous Regions of Taurus and Perseus

The lower eastern part of Plate VI contains some of the masses which belong to the "exterior nebulosities" of the Pleiades. One of these, a roundish spot, is in α 3^h38^m, $\delta+30°0'$. South of this and near the lower edge of the plate are several irregular masses, the brightest of which is in α 3^h35^m, $\delta+28°50'$. It extends in an irregular manner for several degrees east and west. A fainter patch lies in α 3^h32^m, δ $+29\frac{1}{2}°$.

In connection with the above-mentioned objects several other regions near, which are shown on my various photographs, strongly suggest the presence of similar masses of faint nebulosity or obscuring matter. One of these is a semi-vacant region about 9° long and 3° wide, lying northwest by southeast. Its center is in α 4^h16^m, $\delta+37°$. The stars, which are very rich on the southwest side, abruptly cease and continue again on the northeast side, but their limit is not so abrupt. One gets the impression that this partly vacant region is nebulous, but none of the nebulosity is bright enough to show on the plates I have obtained. The nebula N.G.C. 1579 lies on the south side, near the east end of this region. In another less striking region, in an irregular semi-vacant spot about a degree in diameter, is an elongated dark spot 26′ long by 12′ wide, extending nearly north and south in the position α 4^h21^m, δ $+46°21'$. This small spot occurs in a space free from any stars and suggests the presence of some kind of medium different from the stars.

All the positions in this paper are for the epoch 1855.0.

Following are the *B.D.* positions for 1855.0 of the stars mentioned in this paper.

+31°597 (7.0)	α $3^h16^m27^s.9$	δ +31°12′.8
+30 540 (8.8)	3 16 56.8	+31 25.2
+31 599 (7.5)	3 17 34.6	+31 18.7
+29 565 (9.1)	3 19 29.8	+29 16.5
+30 548 (neb.)	3 20 23.8	+30 53.1*
+31 616 (6.5)	3 25 59.8	+31 31.7
+31 619 (7.0)	3 26 38.8	+31 11.5
+31 642 (3.8)	3 35 16.2	+31 49.6†
+31 643 (8.2)	3 35 27.6	+31 42.2

* N.G.C. 1333.

† Omicron Persei.

YERKES OBSERVATORY
WILLIAMS BAY, WIS.
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A COMPARISON OF THE HARVARD AND MOUNT WILSON SCALES OF PHOTOGRAPHIC MAGNITUDE[1]

By FREDERICK H. SEARES

I. INTRODUCTION

For several years the question of standard photographic magnitudes has received much attention at the Harvard Observatory. Announcements of results have been made from time to time,[2] and recently the details and the final magnitudes derived from a long and painstaking investigation, which has been in the hands of Miss Leavitt, have come from the press.[3] In the meantime, the desirability of applying the 60-inch reflector of the Solar Observatory to problems in photographic photometry led to the formulation of methods of observation and reduction adapted for use with that instrument. In order that there might be some control over the results, the first observations were of the stars of the Polar Sequence, which had already been selected by Professor Pickering. Little by little the investigation broadened, and eventually it developed into an independent determination of the photographic and photo-visual scales, not only of the Polar Sequence, but of numerous other stars near the Pole. This investigation is now finished and has been summarized in a previous paper.[4]

A comparison of the Harvard and Mount Wilson results[5] reveals a very satisfactory agreement between the tenth and the fifteenth magnitudes so far as parallelism of the scales is concerned. For both the brighter and the fainter stars there are differences, which, although not greater than might have been anticipated, are sufficient

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 98.

[2] *Harvard Circulars*, Nos. 125, 150, 160, 170 (1907, 1909, 1910, 1912).

[3] *Harvard Annals*, **71**, No. 3, 1914.

[4] *Mt. Wilson Contr.*, No. 97; *Astrophysical Journal*, **41**, 206, 1915.

[5] *Ibid.* The Harvard results referred to are those of *H.C.*, No. 170, or of the twelfth column of Table LXVII of Miss Leavitt's memoir. They define the scale derived from the photographs measured and reduced at the Harvard Observatory.

to introduce an uncomfortable degree of uncertainty into the statistical investigations for which precise magnitudes are required. To avoid this difficulty Miss Leavitt has combined the magnitudes of *H.C.*, No. 170, with preliminary results from Mount Wilson,[1] and with various other determinations covering a limited portion of the scale, thus forming a system of somewhat greater weight than that based upon the Harvard data alone. But this procedure can be regarded only as a temporary expedient, for the outstanding differences are so large as to indicate serious systematic errors, and until these can be traced to their origin and eliminated no sense of security can be attained.

Now that the details of Miss Leavitt's reduction are in print, it is possible to test various hypotheses which might account for the differences between Mount Wilson and the scale of *H.C.*, No. 170; and it is the purpose of this paper to examine critically the data and the results which she has given. A circumstance of great assistance is the fact that we may certainly regard the Harvard scale between the tenth and the fifteenth magnitudes as substantially correct in slope. Not only is the parallelism with Mount Wilson close, but the agreement with the scales of Chapman and Melotte[2] and of Dziewulski[3] is equally good. It is therefore possible to apply to the discussion methods which could not be used for the initial reduction of the data. For example, with the magnitudes between ten and fifteen as an adopted scale, we can in a number of cases derive results for the brighter stars without making any assumption as to the values of the reduction-constants, since these are determined directly from the data, thus eliminating a considerable portion

[1] *Mt. Wilson Contr.*, No. 70; *Astrophysical Journal*, **38**, 241, 1913. In combining the results of *H.C.*, No. 170, with those of Mount Wilson an arbitrary change has been made in the latter between the ninth and tenth magnitudes. Miss Leavitt has interpreted as a break in the scale what appears to be only a consequence of the accidental errors affecting the preliminary magnitudes. As a result, the Mount Wilson determination of the magnitudes of stars fainter than ten, relatively to the international zero-point defined by those of the sixth magnitude, is disregarded, and Miss Leavitt's modified scale below this limit is substantially that of *H.C.*, No. 170.

[2] *Monthly Notices*, **74**, 40, 1913. These results are not independent of the Harvard scale, as they were obtained with the aid of Harvard standard magnitudes. An independent test by means of gratings gave closely accordant results, however.

[3] *Astronomische Nachrichten*, **198**, 65, 1914.

of the errors affecting the individual plates. And by starting from a series of known magnitudes, we can in other cases, namely, those involving exceptionally large values of the constants, avoid certain difficulties which are inherent in the usual process of reduction.

It is thus possible to re-reduce by independent methods a part of the data upon which the Harvard magnitudes are based. An account of this re-reduction will be found in the following pages. The least satisfactory in its results is that part of the present discussion relating to the stars brighter than the tenth magnitude. The deviation for the faint stars, on the other hand, is easily explained. Since the Harvard scale in this region depends exclusively upon Mount Wilson plates which have also been used in determining the Mount Wilson magnitudes, the divergence must be due to differences in measurement and reduction. Such is found to be the case, and the exact point at which they enter is easily specified.

Before proceeding to the detailed discussion of these two divergent regions of the scale, the effect of color upon the Harvard results must be briefly considered.

II. COLOR-CORRECTIONS AND THE ADOPTED SCALE

The Harvard results are based upon 20 groups of plates for each of which magnitudes on an absolute scale were derived by the methods and instruments listed in Table I. These constitute Section A of the results. Four other sections, namely, B, C, D, E, include results from plates which were reduced to the scale of Section A. Section A therefore determines the scale, while the remaining sections afford material for the reduction of the accidental errors affecting individual stars. The mean of the five sections[1] is the scale of *H.C.*, No. 170. A zero-point correction of +0.08 magnitude was subsequently applied and the results were combined with those of other observers to form the final scale of *H.A.*, **71**. It is, however, the mean result from Sections A to E of Miss Leavitt's investigation plus the zero-point correction of 0.08 magnitude, in which we are at present interested. For convenience

[1] Excepting small differences for a few of the faint stars.

this series of magnitudes will be referred to as the Harvard Scale (HS). Hence,

$$\text{HS} = \text{System A to E} + 0.08 = \text{System } H.C., \text{ No. } 170 + 0.08$$

As stated in *Mt. Wilson Contr.*, No. 97, this scale is not altogether homogeneous with respect to the influence of color. For all cases of known color Miss Leavitt has applied corrections which

TABLE I

HARVARD OBSERVATIONS—SECTION A

Group	Mag. Range	Method	Instrument	Δm	Aperture
					mm
1......	2.7– 6.7	Different foci	11-in. Draper	....	....
2......	2.7– 8.7	Iceland spar	8-in. Draper	2.50	....
3......	4.5– 8.9	Pleiades comp.	Various	....	....
4......	6.4–10.6	Praesepe comp.	1-in. Cooke	....	....
5......	2.7–11.3	Screen B2	1-in. Cooke	2.50	....
6......	8.9–15.5	Screen C	16-in. Metcalf	1.55	....
7......	8.9–13.7	Screens C, D, E, B1	16-in. Metcalf	1.15–2.50	....
8......	8.9–13.3	Whole and half ap.	11-in. Draper	0.75	....
9–12...	2.7–14.5	Prismatic comp.	8-in. Draper	5.00	211–25, 20
13......	2.7–14.3	Pleiades comp.	Various	5.00	211–25, 20
14......	2.7– 7.7	Circ. diaphragm	1-in. Cooke	1.50	8, 4
15......	2.7–11.9	Circ. diaphragm	1-in. Cooke	2.28	26.5, 9.3
16......	8.9–14.3	Circ. diaphragm	11-in. Draper	2.00	280, 112
17......	8.9–15.9	Circ. diaphragm	11-in. Draper	2.00	280, 112
18......	16.0–19.0	Circ. diaphragm	60-in. Refl.	4.81	1511–584, 152
19......	10.5–18.9	Circ. diaphragm	60-in. Refl.	2.97	1511–584, 356
20......	10.5–19.1	Circ. diaphragm	60-in. Refl.	2.97	1511–584, 356

reduce the results to the system of the AC (Cooke 1-inch) and I (Draper 8-inch) instruments. But most of the faint stars, whose colors were then unknown, are red or reddish and also require appreciable corrections. The completion of the reduction to a homogeneous color-system therefore first requires our attention. Although a tedious operation, this is easily accomplished with the color-indices now available.

The color-equations of the various instruments were found by comparing the Mount Wilson color-indices[1] with the differences on pp. 196–198 of Miss Leavitt's memoir.[2] Certain equations control-

[1] *Mt. Wilson Contr.*, No. 97; *Astrophysical Journal*, **41**, 206, 1915.

[2] *Op. cit.* For brevity this will be referred to by the letter L followed by the page number.

ling the consistency of the results were also obtained by comparing the Mount Wilson magnitudes with the various groups of Sections A and B in L, 186–188, 195. To avoid the influence of differences of scale for the bright and the faint stars, only those stars between magnitudes ten and fifteen (Nos. 12 to 14*s*, L, 186–188) were used in the comparisons with Mount Wilson. Disregarding constant terms, the results are as shown in Table II.

TABLE II

COLOR EQUATIONS

Equation	Source
MW−MC = +0.33 C	Section A Group 6, 7
MW−C = +0.08 C	" " 17
MW−I = +0.06 C	" " 9–12
MW−I = +0.06 C	" B " 23–30
I−AI = −0.13 C	" B compared with Section C, Gr. 31
I−ACe = +0.10 C	" " " " " " " 32, 34
I−L = +0.14 C	" " " " " " " 37–39
I−MC = +0.24 C	" " " " " " " 48–53
I−ACe red. = −0.07 C	" " " " " D " 62
I−L = +0.28 C	" " " " " " " 64
I−MC = +0.23 C	" " " " " " " 66
I−ACe = −0.14 C	" A and C revised with E " 68

The symbols in the left members of the equations refer to the instruments listed in L, 55. C in the right members is the Mount Wilson color-index. Beginning with the fifth equation, I includes the AC (later 1-inch Cooke) instrument as well as the 8-inch Draper and signifies the standard system chosen by Miss Leavitt. Owing to a lack of data she was unable to make a direct comparison of the color-systems of these two telescopes; but the differences used in deriving the foregoing equations for L (4-inch Cooke), which include AC as well as I results, show that they afford a really homogeneous system.

Although the coefficient for the second L comparison is twice that of the first, the evidence seems unmistakable; the difference shows clearly in both the AC and the I results. Again, the two ACe comparisons give discordant coefficients; but there seems here also to be a real difference, although the first comparison is not very reliable. On the other hand, the large MC (16-inch Metcalf) correction is constant and well determined. Results from the other

instruments appearing in Miss Leavitt's discussion agree sensibly with the standard system.

The next operation was the revision of the mean magnitudes for each of the five sections. Beginning with Section A the results for each group were corrected with the aid of the foregoing equations. The mean magnitudes for individual stars were then formed exactly as described in L, 185, thus giving results which define the homogeneous scale, just as the original results for this section determined the HS. The remaining sections were then similarly treated, and finally each received a correction to reduce it to the revised scale of Section A, a procedure necessitated by the fact that the color-corrections modify the results for the different sections by different amounts. This reduction was made graphically, and the results for all sections were then collected in a table similar to that in L, 207–209. The weighted means were then found for each star in the manner followed by Miss Leavitt (L, 206) and corrected by +0.08 mag. for zero-point, thus giving what may be called the Harvard Homogeneous Scale (HH). In revising the results care was taken throughout to make allowance for the color-corrections already applied by Miss Leavitt (L, 204).

The agreement of the results from the different sections was very good before the revision, the average deviation of the mean magnitude for a single section being only 0.022 mag.; the reduction to a homogeneous system has decreased this to 0.019 mag., which is an indication of the remaining accidental errors. The main significance of the results, however, is to be found in the fact that, owing to the systematic dependence of color upon magnitude,[1] the scale itself has been appreciably modified. The amount of this change is indicated by the quantities in the fourth column of Table III. The application of these corrections to the values of HS gives the Harvard Homogeneous magnitudes in the HH column.

The comparisons of Mount Wilson with the original results for Sections A and B revealed an appreciable color-equation between the Mount Wilson and AC-I systems. This same relation should

[1] *Mt. Wilson Contr.*, No. 81; *Astrophysical Journal*, **39**, 361, 1914.

appear from the differences MW−HH in Table III; and, in fact, we find

$$MW-HH=+0.24+0.06\ C,$$

which is in agreement with the results in Table II. Star 11*s* (MW 15.31) was the faintest object used in deriving this relation, although all the brighter objects excepting 1*s* were included after applying a correction for scale-difference between HH and MW. This correction has the form

$$MW-HH=+0.061\ (HH-10),$$

which holds for objects brighter than 10.

For the final comparison of the Harvard and Mount Wilson results, we must reduce them to the same color system by means of the first of the foregoing equations. The necessary corrections for the reference of HH to the Mount Wilson system are in the column headed HH_w-HH, and their subtraction from MW−HH shows the outstanding differences of scale between Mount Wilson and Harvard. These appear under the heading $MW-HH_w$ in Table IX of *Mount Wilson Contr.*, No. 97; but for the purpose of the present paper it is convenient to have the two scales coincide from the tenth magnitude onward. On this account the constant term of 0.24 in the color equation was also taken into account in forming the differences $MW-HH_w$ in Table III.

By way of recapitulation, the latter differences indicate the relation between the Harvard (HS) and Mount Wilson scales after the former has been subjected to the following operations: (1) reduction to a homogeneous color system; (2) correction for color to reduce to the MW system; (3) correction for zero-point to produce coincidence with MW in the region of parallelism (mags. 10–15). The last column of Table III shows that in the intermediate region the agreement is very satisfactory. Between the ninth and sixteenth magnitudes there are but two differences exceeding 0.10 mag., namely, those from the red stars 4*r* and 6*r*.

Neither of the color-corrections is very large, but together they form an appreciable quantity, which is important because of its differential effect between bright and faint stars. Both enter in a direction such as to decrease the original divergence between HS

TABLE III

Corrections for Color and Comparison of Scales

Star	MW	HS	HH *minus* HS	HH	CI	MW *minus* HH	HH_W *minus* HH	MW *minus* HH_W
1*s*	2.54	2.79	....	(2.79)	0.46	(−25)	....	(−49)
1	4.39	4.55	0	4.55	0.02	−16	0	−40
2	5.30	5.32	−1	5.31	0.02	−1	0	−25
3	5.83	5.82	0	5.82	0.27	+1	+2	−25
4	5.91	5.99	0	5.99	0.07	−8	0	−32
2*s*	6.45	6.46	0	6.46	0.12	−1	+1	−26
5	6.45	6.47	0	6.47	−0.02	−2	0	−26
3*s*	6.64	6.62	+1	6.63	0.29	+1	+2	−25
1*r*	6.61	6.77	+1	6.78	1.52	−17	+9	−50
6	7.11	7.06	+1	7.07	0.06	+4	0	−20
7	7.41	7.26	0	7.26	−0.11	+15	−1	−8
2*r*	7.94	7.82	−1	7.81	1.59	+13	+10	−21
8	8.32	8.18	+2	8.20	0.19	+12	+1	−13
3*r*	8.96	8.70	+1	8.71	1.40	+25	+8	−7
9	8.88	8.78	+1	8.79	0.07	+9	0	−15
10	9.12	8.97	0	8.97	0.05	+15	0	−9
4*r*	9.22	9.05	0	9.05	0.96	+17	+6	−13
11	9.73	9.50	+2	9.52	0.20	+21	+1	−4
12	10.09	9.81	+2	9.83	0.29	+26	+2	0
5*r*	10.13	9.86	+2	9.88	1.48	+25	+9	−8
4*s*	10.25	10.07	−1	10.06	0.42	+19	+2	−7
13	10.53	10.25	+1	10.26	0.16	+27	+1	+2
6*r*	10.46	10.25	+2	10.27	1.25	+19	+8	−13
14	10.98	10.60	+2	10.62	0.44	+36	+3	+9
7*r*	10.94	10.65	+1	10.66	1.04	+28	+6	−2
5*s*	11.09	10.76	+1	10.77	1.03	+32	+6	+2
15	11.22	11.02	+1	11.03	0.33	+19	+2	−7
6*s*	11.38	11.05	+3	11.08	0.65	+30	+4	+2
8*r*	11.44	11.14	0	11.14	1.00	+30	+6	0
16	11.62	11.34	+1	11.35	0.39	+27	+2	+1
17	11.87	11.57	+4	11.61	0.59	+26	+4	−2
9*r*	....	11.64	+2	11.66	1.20	....	+7	....
18	12.27	12.00	+3	12.03	0.38	+24	+2	−2
10*r*	....	12.29	+3	12.32	0.72	....	+4	....
7*s*	12.61	12.39	+3	12.42	0.51	+19	+3	−8
19	12.69	12.36	+3	12.39	0.41	+30	+2	+4
20	13.02	12.67	+3	12.70	0.51	+32	+3	+5
21	13.33	12.90	+9	12.99	0.85	+34	+5	+5
11*r*	13.22	12.91	−1	12.90	1.16	+32	+7	+1
22	13.44	13.13	+5	13.18	0.63	+26	+4	−2
23	13.60	13.28	+4	13.32	0.50	+28	+3	+1
12*r*	13.84	13.42	+3	13.45	1.38	+39	+8	+7
24	13.93	13.58	+3	13.61	0.60	+32	+4	+4
25	14.08	13.81	+2	13.83	0.48	+25	+3	−2
8*s*	14.49	14.14	+4	14.18	0.71	+31	+4	+3
26	14.64	14.27	+4	14.31	0.92	+33	+6	+3
9*s*	14.75	14.41	+4	14.45	0.90	+30	+5	+1
27	14.91	14.63	+3	14.66	0.58	+25	+3	−2
10*s*	15.29	14.96	+3	14.99	0.80	+30	+5	+1
11*s*	15.31	14.99	+4	15.03	0.96	+28	+6	−2
28	15.27	15.05	+3	15.08	0.73	+19	+4	−9

TABLE III—*Continued*

Star	MW	HS	HH *minus* HS	HH	CI	MW *minus* HH	HH_W *minus* HH	MW *minus* HH_W
12*s*....	15.33	15.05	+3	15.08	0.64	+25	+ 4	− 3
13*s*....	15.54	15.17	+4	15.21	1.00	+33	+ 6	+ 3
29.....	15.82	15.60	+2	15.62	0.61	+20	+ 4	− 8
14*s*....	15.99	15.69	+3	15.72	0.92	+27	+ 6	− 3
30.....	16.18	15.98	+2	16.00	0.74	+18	+ 4	−10
31.....	16.41	16.16	+2	16.18	0.79	+23	+ 5	− 6
15*s*....	16.57	16.36	+1	16.37	0.86	+20	+ 5	− 9
32.....	16.76	16.56	+1	16.57	1.18	+19	+ 7	−12
16*s*....	16.86	16.66	+1	16.67	1.36	+19	+ 8	−13
33.....	17.06	16.90	+2	16.92	1.09	+14	+ 7	−17
17*s*....	17.19	17.05	+1	17.06	1.30	+13	+ 8	−19
34.....	17.24	17.19	0	17.19	0.95	+ 5	+ 6	−25
35.....	17.63	17.44	+2	17.46	0.69	+17	+ 4	−11
36.....	17.78	17.69	−1	17.68	0.98	+10	+ 6	−20
37.....	18.01	17.88	−1	17.87	1.20	+14	+ 7	−17
18*s*....	17.94	17.85	−2	17.83	1.03	+11	+ 6	−19
38.....	18.20	18.25	−2	18.23	1.15	− 3	+ 7	−34
19*s*....	18.16	18.44	−3	18.41	1.21	−25	+ 7	−56
39.....	18.58	18.61	−3	18.58	1.45	0	+ 9	−33
20*s*....	18.60	18.64	−3	18.61	1.41	− 1	+ 8	−33
21*s*....	18.66	18.82	−4	18.78	1.33	−12	+ 8	−44
22*s*....	18.75	18.87	−4	18.83	1.62	− 8	+10	−42
23*s*....	18.70	19.05	−5	19.00	1.29	−30	+ 8	−62
24*s*....	18.88	18.96	−8	18.88	1.54	0	+ 9	−33
40.....	18.87	18.97	−4	18.93	1.58	− 6	+ 9	−39
25*s*....	18.84	19.11	−5	19.06	1.46	−22	+ 9	−55
41.....	19.02	19.22	−5	19.17	1.55	−15	+ 9	−48

and MW for the bright stars. Thus the unexplained difference between the sixth and tenth magnitudes has been reduced from 0.40 mag.[1] to 0.24 mag.

We now turn to the question whether this remaining divergence, as well as that for the faint stars, is capable of further reduction. In accordance with the explanation on p. 260 we adopt for this investigation, as accurately known, the HH magnitudes between ten and fifteen, and proceed first to an extension of this scale in the direction of the brighter stars.

III. THE DIVERGENCE FOR THE BRIGHT STARS

An examination of Table I shows that the groups of observations there listed may be classified as follows: (*a*) Groups 1–4 and 14, including stars brighter than the ninth magnitude (approximately);

[1] *Mt. Wilson Contr.*, No. 97, p. 16; *Astrophysical Journal*, **41**, 221, 1915.

(*b*) Groups 6–8, 16, and 17, including stars fainter than the ninth magnitude; (*c*) Groups 5, 9–13, and 15, which connect the results from (*b*) with those of (*a*).

The range in (*c*) is from about the third to the fourteenth or fifteenth magnitudes. The zero-point of the magnitudes fainter than 9 depends wholly upon the connecting groups in this division. Groups 18–20 include the fainter stars and are not considered here.

Since the Harvard scale, except for accidental errors, depends exclusively upon the observations of Section A, it is necessary to examine in detail the data for the above-mentioned groups. These we now consider in the order specified.

a) Groups 1–4 and 14

The reductions for this division have not been carefully examined as it is not possible to apply here independent methods of reduction; moreover, the data are not always accessible. The agreement for the different groups is good (see residuals L, 187), although individual plates are sometimes rather discordant (L, 153). One would anticipate that accordance of results by such widely different methods as varying foci, Iceland spar, and circular diaphragms would be strong evidence of a high degree of precision in the mean scale. But we also find close agreement among the Göttingen, Yerkes, and Mount Wilson results[1] for this region (4.0–7.5), and yet these three series of magnitudes show a mean divergence of about 6 per cent from the Harvard scale.

It is of interest to note that the same divergence between Harvard and Göttingen appears when the results for the Pleiades are compared. The Harvard magnitudes for the latter region were derived from Iceland spar and prismatic companion-plates (L, 53, 154, 176) and have been used for the reduction of Groups 3 and 13 of the Polar Sequence. Their deviations from the Göttingen results are shown in the fifth column of Table IV. Inasmuch as the Göttingen series[2] does not include fainter stars, I have extended the scale to the ninth magnitude with the aid of Schwarzschild's Vienna observations.[3]

[1] *Mt. Wilson Contr.*, No. 97. [2] *Aktinometrie*, B, p. 14, 1912.

[3] "Beiträge zur photographischen Photometrie der Gestirne," *Publ. der von Kuffner'schen Sternwarte*, **5**, 62, 1900.

For further comparison, Hertzsprung's magnitudes[1] of the brighter Pleiades stars (diminished by 0.26 mag.) are also included in Table IV. Although derived by different methods, the Göttingen and Hertzsprung series are in close agreement, and hence the latter also shows the characteristic deviation from Harvard.

TABLE IV

COMPARISON OF SCALES FOR THE PLEIADES

Harvard No.	Bessel No.	Gött.	Hertz.	Gött.−H.	Hertz.−H.
1	η	2.87	2.85	−14	−16
2	*f*	3.57	3.59	− 9	− 7
3	*b*	3.59	3.67	− 8	0
4	*c*	3.82	3.85	−12	− 9
5	*d*	4.21	4.13	− 7	−15
6	*e*	4.22	4.20	− 7	− 9
7	*h*	4.94	....	+ 4	....
8	*g*	5.37	5.38	+ 5	+ 6
9	*k*	5.69	5.70	− 3	− 2
10	*l*	6.35	6.34	+ 4	+ 3
11	24	6.84	6.87	+ 3	+ 6
12	29	7.02	7.01	+ 2	+ 1
13	4	7.25	7.28	− 1	+ 2
14	10	7.43	7.38	+ 6	+ 1
15	39	7.57	7.52	+16	+11
16	37	7.70	7.55	+14	− 1
17	33	8.15	8.14	+16	+15
18	....	....	8.67	....	+28
19	21	8.94	8.82	+25	+13
20	....	....	8.86	....	+ 6
21	2	9.00	8.95	+14	+ 9
23	36	9.26	9.10	+10	− 6

Some caution must be exercised, however, in judging of scale differences in cases like the present, for there is a progressive change in color with increasing magnitude, and hence a possibility of confusing a color-equation with differences in scale. An examination of the circumstances seems to exclude such an explanation, however.

b) Groups 6–8, 16, and 17

As the scales established by these groups usually begin at the ninth magnitude, they cover but one magnitude of the divergent region which includes the brighter stars. The calculation for the

[1] *Astronomische Nachrichten*, **186**, 181, 1910.

few stars falling within this interval is easily controlled with the aid of the adopted magnitudes in the region 10–15.

The plates show at least two exposures—full aperture (*a*) and reduced aperture (*b*). The Harvard scale readings for (*a*) and (*b*) were plotted against the adopted magnitudes as ordinates, beginning in each case with Star 13 (10.26). The two curves thus defined should be parallel, and the difference in corresponding ordinates should equal the reduction constant Δm. Any deviation from parallelism, or any lack of agreement with the adopted constant Δm, indicates an abnormality which must affect the scale derived from the plate in question. Non-parallelism of the curves signifies differences in gradation for the two exposures. Lack of equality between the ordinate-difference and Δm means that the effective reduction-constant differs from the adopted value. This may be caused by changes in transparency or in the sensitiveness of the plate during the exposures. With the method of reduction here used this is of no consequence, for as long as the curves are parallel, or nearly so, it is only necessary to displace the *a*-curve vertically until it coincides with the *b*-curve. This automatically extends the *b*-curve into the region of smaller scale-readings and gives a curve from which the magnitudes of the brighter stars of the *b*-exposure may be interpolated. The results are independent of changes in transparency, of the phenomenon affecting first and last exposures,[1] and of errors in the adopted reduction-constants.

By an extension of this process it is also possible to make use of scale-readings upon the images of the bright stars shown by the *a*-exposure, when such are present. This tends to diminish the accidental errors, but does not otherwise contribute toward a knowledge of the scale. A complete reduction of all the plates was made by both processes before the necessity of a detailed examination of the influence of color became apparent, although only the results by the simpler process first outlined have been used. A third reduction was subsequently made for Groups 6 and 7, which relate to the Metcalf 16-inch and are most likely to be influenced by color. But inasmuch as the first two reductions had been based upon white stars alone, the final reduction of Groups 6 and 7, in which

[1] *Mt. Wilson Contr.*, No. 64, p. 7; *Astrophysical Journal*, **36**, 374, 1912.

the influence of color was taken into account, made no appreciable difference.

Nearly all of the plates in the five groups of this division appear to be of very satisfactory quality. The magnitude-curves deviate from parallelism by only a few hundredths of a magnitude, and in all cases the calculated reduction-constant is nearly equal to the value adopted by Miss Leavitt.

The results for each plate are shown in Table V in the form of corrections to the HH magnitudes of Table III. The last two lines exhibit the agreement between the observed and the theoretical reduction-constants. The first series of values for Plate 229 depends upon the mean of two reduced-aperture exposures with screens C and D, respectively (L, 159), and has accordingly been given double weight. Plate 186 has also received double weight because of exceptional quality (L, 63) and duplicate measures. In addition to the four stars listed in Table V, corrections were derived from Plate 248 for four others as follows:

No. 6, −21; No. 2*r*, −29; No. 8, −24; No. 9, −24

The mean corrections are characterized by a rather marked persistence of the negative sign. The probable errors, which are expressed in thousandths of a magnitude, suggest that the HH magnitude for Star 10, and perhaps that for No. 12, actually require small corrections.

c) The Connecting Groups 5, 9–13, and 15

We now consider the important groups connecting the bright stars with those fainter than the tenth magnitude. With the exception of Group 13, the data have been independently reduced, partly by methods equivalent to those used by Miss Leavitt, and partly by other processes.

Group 5 (wire screen B2, $\Delta m = 2.50$, on 1-inch Cooke anastigmat, two exposures of 30^m).—Since the faintest star registered on the three plates of this group is 11.2, the magnitudes between 10 and 15 are of no assistance in deriving the scale or in testing the value of the reduction-constant. The usual method of reduction[1] has therefore been applied.

[1] *Mt. Wilson Contr.*, No. 80, p. 24; *Astrophysical Journal*, **39**, 330, 1914.

TABLE V

CORRECTIONS TO IIII FROM DIVISION (*b*)

Star	Group [illegible]			Group 7					Group 8				Group 16			Group 17		Mean	P.E.	Wt.
	231	232	233	229		240	243	248	166	167	170	171	182	184	185	186	194			
10........	−10	−22	+5	−26	−23	−13	+7	−3	−24	+11	+24	−9	−6	−15	−6	−10	−12	−9	019	19
11........	−2	+24	+3	−15	−6	−5	+14	+14	.....	.....	−6	.....	.....	+9	−5	−2	+3	+1	018	15
12........	−9	+17	0	−27	−8	−1	+2	+8	−3	−18	−5	+15	−5	+2	−6	−11	+9	−4	017	19
45........	−19	+6	+11	+5	−14	−20	+6	0	.....	.....	−15	.....	.....	.....	.....	.....	+1	−3	026	11
Obs. Δm..	1.60	1.50	1.43	1.50	1.12	1.52	2.40	2.52	0.73	0.72	0.77	0.80	2.00	1.95	1.90	2.10	1.86			
Theor. Δm.	1.55	1.55	1.55	1.56	1.15	1.55	2.50	2.50	0.75	0.75	0.75	0.75	2.00	2.00	2.00	2.00	1.90			

Although there are differences for individual plates, the mean scale for the group is substantially that found by Miss Leavitt, from which it may be inferred that our reduction-processes are equivalent. The zero-point was determined by making the mean magnitudes of the eight or ten stars fainter than magnitude 10 equal to the mean of the corresponding HH magnitudes. For stars brighter than magnitude 10 there is a preponderance of negative corrections (i.e., the HH magnitudes are relatively too faint) and a divergence in the direction of the Mount Wilson results (compare residuals, L, 187).

A point of fundamental importance is the reduction-constant, which was calculated from the measured dimensions of the mesh on the assumption that the absorption in magnitudes for point sources is twice that for luminous surfaces. The screen is of rather fine wire gauze (L, 159): wires 0.0940 mm, spaces 0.1206 mm), and for dimensions such as these the assumption that the constant, Δm, is twice the absorption for luminous surfaces is not entirely justifiable. Du Bois and Rubens have investigated the question[1] and their results indicate that for this case the double of the absorption for surfaces should be increased by 0.05 mag., in order to obtain the constant for point-sources. This correction makes the magnitudes of the bright stars relatively brighter, the change between 6 and 10 being 1.6 times the correction, or 0.08 mag. The final results, which are based upon the revised constant ($\Delta m = 2.55$), appear in the fourth column of Table X. As before, they are expressed as corrections which, applied to the HH magnitudes, will yield the values derived from the re-reduction of the group.

Groups 9–12 (prismatic companions, with the 8-inch Draper telescope).—For Groups 9–11, the exposures, with one exception, were 10^m. For Group 12, they were 60^m, excepting two plates which received 93^m and 120^m, respectively. The reduction-constant calculated from the clear aperture of the prism (cemented to the center of the objective) and the unobstructed area of the objective is 5.10 magnitudes. This requires correction for differential absorption owing to the different thicknesses of glass traversed by the two beams—that directly transmitted and that deflected by the

[1] *Annalen der Physik*, **49**, 593, 1893.

prism. It was not found possible to determine this directly, and in consequence the following procedure was adopted (L, 172):

> It was shown above that the center of the objective of the 11-inch Telescope transmits more light than the average for the entire lens by at least 0.1 magn. If we assume a similar effect in both the lenses of which the 8-inch Draper Doublet is composed, we shall have a correction of −0.2 magn. to the computed difference. On the other hand, we may allow a loss of light of 0.1 magn. arising from the reflection and absorption of the small prism. The adopted difference is $5.1-0.2+0.1=5.0$.

The fact that the absorption for the center of the 11-inch Draper objective is less than the average for the whole objective indicates that the main factor involved is not absorption in the ordinary sense, but residual aberrations in the optical system. These, however, are peculiar to each instrument; and the assumption that what applies to the 11-inch Draper also applies, and in the manner indicated, to the 8-inch instrument, seems open to question. One is therefore inclined to suppose that the adopted value of the constant is subject to some uncertainty. The circumstance is unfortunate, as the bulk of the material (23 plates) connecting the fainter stars with the international zero-point is contained in these four groups.

The matter is further complicated by the fact that the reduction of plates involving so large a constant presents special difficulties. These are pointed out by Miss Leavitt, and to meet them in so far as possible she has employed a special process (L, 147).

The uncertainty arising from this source can now be removed by a method similar to that described on p. 270. With the aid of the adopted scale between 10 and 15 we can derive for the brighter stars magnitudes which are free from systematic errors arising from the reduction-process; but in this instance we are obliged to assume the validity of the reduction-constant, for only a few of the brighter stars of known magnitude show prismatic companions.

We plot the scale-readings of the primary exposures against the HH magnitudes which are fainter than 10, and read from the curve thus defined the magnitudes corresponding to the scale-readings of the prismatic companions. The subtraction of five magnitudes from each value gives the required results. Prismatic companion

readings which do not fall within the limits of the curve cannot at once be utilized. Nor can the readings upon bright stars of the primary exposure be used directly; but by plotting these against the corresponding magnitudes found by the process just described, a curve will be defined which should be an extension of that originally drawn. If, however, an erroneous value of Δm has been used, or if there are differences of gradation between the two exposures, a discontinuity will occur, and the curves must be adjusted so that a smooth junction is effected.

The use of the adjusted curves tends to eliminate gradation-differences and reduce the accidental errors of observation, but in the mean of several plates probably does not materially affect the result. They have not been used in the present case, because the majority of the bright stars are beyond the limit of distance from the center of the plate for which the primary images may be used, and, further, because it was desired to bring into view any peculiarities affecting the method of prismatic companions.

The corrections to the HH magnitudes for the individual plates of the four groups are in Tables VI and VII. The preponderance of negative signs is at once evident and indicates a systematic difference between the results of the present reduction and that of Miss Leavitt. The difference appears clearly in the mean residuals for Groups 9–11, although not in those of Group 12 (Table VIII). For individual plates, the difference is not constant, but shows a marked progression—see, for example, Plate 84 of Group 9 and Plate 116 of Group 12—which suggests either differences in gradation between the two series of images or systematic errors of measurement which easily arise when the secondary images are not closely comparable with those of the primary series. A difference in the slope of the HH scale for the bright stars as compared with that in region of magnitudes 10 to 15 would also produce a progressive change in the residuals; but any such progression would be the same for all the plates.

The systematic difference between the mean residuals for Groups 9–11 and Group 12 is rather remarkable. Two circumstances may be noted: first, the average exposure-time for the last group was about six times that for the others, and, second, four of the plates of

Group 12 either presented some abnormality or were difficult to measure (L, 102, remarks). On the other hand, Plates 98 and 103

TABLE VI

RESIDUALS, GROUPS 9 AND 10

Star	Group 9					Group 10				
	84	85	94	95	104	105	106	107	113	118
2s	+14	−18	+ 8	+16	+ 8	.....	.....	.....	.....	.....
5	+13	+ 1	+11	+ 6	−23	−34	−27	−27	−17	+ 6
6	+15	+ 1	−13	−14	+16	−29	+ 2	−23	−13	+14
7	+16	−24	−23	+32	− 4	.....	−18	−27	−18	−13
2r	−18	−15	− 5	−14	.....	−25	+ 9	−26	−13	−13
8	−24	−22	−20	−51	− 7	− 5	− 5	− 6	−30	+ 7
3r	−27	−11	− 2	−24	.....	.....	.....	.....	.....	.....
9	−14	− 9	−22	−10	− 7	+ 8	−12	−48	+ 5	− 3
10	−43	− 6	− 9	−41	−16	−18	−19	− 5	+ 9	−28
4r	.....	.....	− 4	−37	− 5	−19	−32	−47	− 7	− 5
11	−25	+15	+ 7	− 8	0	.....	−26	−19	.....	−33
12	.....	− 5	− 3	−18	.....	.....	−26	−39	.....	.....
5r	.....	.....	.....	−16	.....	.....	.....	.....	.....	.....
4s	.....	.....	.....	−17	.....	.....	.....	.....	.....	.....

TABLE VII

RESIDUALS, GROUPS 11 AND 12

Star	Group 11					Group 12							
	97	98	99	103	109	108	114	121	148	150	115	116	117
2s	.....	−24	.....	+ 2	.....	.....	.....	+24	.....	.....	.....	.....	....
5	+10	−21	.....	−21	−42	+23	+ 1	+23	+37	+68	+ 5	−14	+ 3
1r	.....	.....	.....	.....	.....	.....	−33	.....	.....	.....	.....	.....	....
6	+ 8	−27	−41	−12	+ 4	+12	0	+25	−11	+20	+18	−21	+ 4
7	.....	−29	.....	−17	+ 9	−15	− 6	+40	.....	.....	.....	0	....
2r	+19	−10	−26	−33	+ 6	.....	−21	+17	.....	.....	− 3	− 3	+ 7
8	+14	−20	− 4	−54	− 5	−29	− 9	+24	+26	+ 9	−22	+11	− 4
3r	.....	+ 4	.....	−34	.....	−17	.....	+ 4	.....	.....	.....	+ 3	....
9	+ 2	.....	− 1	−39	+18	−15	−10	+ 5	0	−18	−17	+ 5	− 3
10	−27	−12	− 9	− 4	+21	−13	+ 2	−14	− 9	+ 1	− 8	− 2	+19
4r	.....	−34	.....	−25	+13	−32	− 6	− 2	.....	.....	− 6	+13	+32
11	.....	.....	−13	−35	−12	− 4	−21	+ 4	+25	− 6	− 8	+ 6	+20
12	.....	.....	.....	.....	.....	−44	+14	− 6	+13	+ 5	−29	− 1	+ 1
5r	.....	.....	.....	.....	.....	+16	.....	− 1	.....	.....	.....	+11	....
4s	.....	.....	.....	.....	.....	−39	−12	−22	− 2	−21	− 8	+31	−37

were measured more than the usual number of times and by two different observers (L, 62, 63).

One is tempted to speculate as to the possibility of an influence depending upon exposure-time, for it is conceivable that the image of a prismatic companion might increase in diameter with increasing exposure at a rate different from that of the image produced by the remainder of the objective; but the data are too slender to permit any definite conclusion.

Group 13.—The results from this group were obtained by comparisons of the Pole with the Pleiades, for which a scale was established by the method of prismatic companions. As there are no

TABLE VIII

MEAN RESIDUALS, GROUPS 9-12

Star	HH Mag.	Mean Residuals				No. Values	Wtd. Mean	P.E.	Wt.
		9	10	11	12				
2s.........	6.46	+ 6	.....	−11	+24	5, 0, 2, 1	+ 4	038	8
5..........	6.47	+ 2	−20	−18	+18	5, 5, 4, 8	− 1	035	22
1r.........	6.78	.....	.....	.....	−33	0, 0, 0, 1	−33	.....	1
6..........	7.07	+ 1	−10	−14	+ 6	5, 5, 5, 8	− 3	027	23
7..........	7.26	− 1	−19	−12	+ 5	5, 4, 3, 4	− 6	034	16
2r.........	7.81	−13	−14	− 9	− 1	4, 5, 5, 5	− 9	024	19
8..........	8.20	−25	− 8	−14	+ 1	5, 5, 5, 8	−10	028	23
3r.........	8.71	−16	.....	−15	− 3	4, 0, 2, 3	−12	035	9
9..........	8.79	−12	−10	− 5	− 7	5, 5, 4, 8	− 8	019	22
10..........	8.97	−23	−12	− 6	− 3	5, 5, 5, 8	−10	020	23
4r.........	9.05	−15	−22	−15	0	3, 5, 3, 6	−12	035	17
11..........	9.52	− 2	−26	−20	+ 2	5, 3, 3, 8	− 7	026	19
12..........	9.83	− 9	−32	.....	− 6	3, 2, 0, 8	−11	037	13
5r.........	9.88	−16	.....	.....	+ 9	1, 0, 0, 3	+ 2	046	4
4s.........	10.06	−17	.....	.....	−14	1, 0, 0, 8	−14	041	9
Mean.....	....	− 9	−16	−12	0		− 7		

Mount Wilson results for the Pleiades, a direct comparison cannot be made, but the divergence of the Harvard magnitudes for this region from those of Göttingen and Potsdam has already been referred to in connection with Table IV. As the method used for Groups 9-12 and several of the plates included in Group 11 (Nos. 97-99, 103) were also used for Group 13, it is to be inferred that the results found above also apply here.

Group 15.—This includes four plates taken with a circular diaphragm of 9.3 mm placed centrally over the 26.5 mm objective of a Cooke anastigmat. Two exposures of 45^{m} were made on each

plate. The calculated constant, 2.28 magnitudes, was used without correction for differential absorption within the objective. A re-reduction by the normal method, using the foregoing value of the constant, gives substantially the result found by Miss Leavitt. For two of the plates, however, the deviations are very large (see residuals, L, 178).

To test further the agreement with the HH scale, readings for both diaphragm and full aperture exposures were plotted against the HH magnitudes, using all the stars measured. From the two curves thus defined were read the differences in the ordinates for each half-interval of scale-reading. The deviations of these observed values of Δm from the adopted constant are shown in Table IX. The agreement for Plate 54 alone is really satisfactory,

TABLE IX

GROUP 15, OBSERVED Δm — ADOPTED Δm

Scale Reading	Plate 54	Plate 55	Plate 56	Plate 58
3.0	....	−23	....	....
3.5	....	−18	....	....
4.0	+7	−21	+26	....
4.5	+4	−23	+20	....
5.0	+2	−26	+12	+49
5.5	+2	−26	+ 5	+46
6.0	+2	−28	+ 6	+42
6.5	+2	−28	0	+42
7.0	−3	−28	+ 3	+41
7.5	−5	−20	+ 3	+32
8.0	−3	−16	+ 7	+16
8.5	−4	−13	+17	− 8
9.0	−4	0	+22	−13
9.5	−6	+11	+12	− 8
10.0	0	+16	− 3	+ 2

while Plates 55 and 58 are seriously discordant. Although the errors for these two balance each other, they reduce considerably the weight of the mean scale for the group. Changes in the observed reduction-constant of the character of those shown in Table IX are an indication of differences in gradation or of lack of comparability in the two series of images. Their appearance in the present instance is not surprising in view of the long exposures involved. In addition to these irregularities there is the uncertainty in the reduction-constant arising from differential absorption,

so that Group 15 contributes little weight to the determination of the scale.

Summary for plates connecting bright stars with those fainter than the tenth magnitude.—The preceding paragraph completes the discussion of the data which connect the faint stars with those in the vicinity of the sixth or seventh magnitude. As the zero-point for all the fainter objects must be derived through this connection, its importance for the final scale is obvious. In the region covered there is considerable difference between the HH and MW scales, and the data and reductions have been examined for evidence which might afford an explanation of the divergence. The following summarizes the results:

Three methods have been employed—a wire gauze screen, prismatic companions, and a circular diaphragm. In none of these is it clear that the reduction-constant is certainly free from suspicion. That of the screen is derived from measures of the mesh and apparently requires a correction of +0.05 magnitude. In the case of the other two methods, differential absorption in the objective is not wholly accounted for; for the prismatic-companion plates a correction of doubtful validity is used, while for the diaphragm plates the effect is disregarded altogether. As for the prismatic companion constant, the error is probably small in spite of the assumptions involved, otherwise the portion of the scale below the tenth magnitude thus established would not agree so well with the HH scale, which in this region must be accepted as substantially correct.

With the revised screen-constant, we find that the scale thus established agrees closely with MW (compare MW−HH, Table III, with corrections in the fourth column of Table X). Re-reducing the prismatic companion plates with the aid of the adopted scale from 10 to 15, we find a systematic deviation from the Harvard Homogeneous Scale in the direction of the Mount Wilson results, but less, in the mean, than the differences between HH and MW. The examination of the diaphragm plates in Group 15 shows that the mean result agrees well with HH; but two of the plates show serious internal inconsistencies. On the whole, the re-reduction of the connecting plates points toward the necessity for some

correction of the HH scale in the region of the brighter stars. The indicated change is in the same direction as that derived by comparison with MW, but somewhat less in amount.

d) Results of the Re-reduction

The corrections to the HH magnitudes found in sections *a*), *b*), and *c*) for all of the groups re-reduced excepting No. 15 are brought together in Table X, their relative weights (number of values)

TABLE X

COLLECTED RESULTS OF RE-REDUCTION—CORRECTIONS TO HH MAGNITUDES

Star No.	HH Mag.	Re-reduction *minus* HH: Gr. 6–8, 16, 17	Gr. 5	Gr. 9–12	Wtd. Mean	Wt.	MW *minus* HH_W	MW *minus* Re-reduction
1*s*...	(2.79)	....	−53 (3)	....	−53	3	(−49)	(+ 4)
1....	4.55	....	−33 (3)	....	−33	3	−40	− 7
2....	5.31	....	−30 (3)	....	−30	3	−25	+ 5
3....	5.82	....	−20 (3)	....	−20	3	−25	− 5
4....	5.99	....	−20 (3)	....	−20	3	−32	−12
2*s*...	6.46	....	−19 (3)	+ 4 (8)	− 2	11	−26	−24
5....	6.47	....	−22 (3)	− 1 (22)	− 4	25	−26	−22
3*s*...	6.63	....	−15 (3)	....	−15	3	−25	−10
1*r*...	6.78	....	−20 (3)	−33 (1)	−23	4	−50	−27
6....	7.07	−21 (1)	−14 (3)	− 3 (23)	− 5	27	−20	−15
7....	7.26	....	− 3 (3)	− 6 (16)	− 6	19	− 8	− 2
2*r*...	7.81	−29 (1)	−13 (3)	− 9 (19)	−10	23	−21	−11
8....	8.20	−24 (1)	+ 2 (3)	−10 (23)	− 9	27	−13	− 4
3*r*...	8.71	....	− 6 (3)	−12 (9)	−10	12	− 7	+ 3
9....	8.79	−24 (1)	−17 (3)	− 8 (22)	−10	26	−15	− 5
10....	8.97	− 9 (19)	−13 (3)	−10 (23)	−10	45	− 9	+ 1
4*r*...	9.05	....	−12 (3)	−12 (17)	−12	20	−13	− 1
11....	9.52	+ 1 (15)	−14 (3)	− 7 (19)	− 4	37	− 4	0
12....	9.83	− 4 (19)	+ 3 (3)	−11 (13)	− 6	35	0	+ 6
5*r*...	9.88	....	− 8 (3)	+ 2 (4)	− 2	7	− 8	− 6
4*s*...	10.06	− 3 (11)	− 8 (3)	−14 (9)	− 8	23	− 7	+ 1

being indicated by the quantities in parentheses. Had Group 15 been included, several of the mean corrections in the sixth column would have been decreased one- or two-hundredths of a magnitude; but this change probably would have been offset by one in the opposite direction had it been possible to reduce Group 13 by the foregoing methods. In view of the uncertainties affecting Group 15 it is likely that the results are more reliable as they stand.

The agreement from the seventh magnitude downward of the third, fourth, and fifth columns seems to show pretty clearly the necessity for corrections of the order indicated; but the relation of the fainter HH magnitudes to the international zero-point is unfortunately less definitely established. The results from the prismatic-companion plates (Groups 9–12), which are the most numerous of all the connecting plates, become relatively uncertain just at the critical point, for here the magnitudes are at the end of the scale derived from these groups. The only groups in Miss Leavitt's data which satisfactorily cover the questionable region are Nos. 3, 5, 13, and 15. The last appears to be unreliable for reasons given above. Nos. 3 and 13 involve comparisons with the Pleiades, and, although accordant with each other, do not agree with the results from Group 5.

The corrections in the sixth column, with the exception of that for Star 12, are all such as to decrease the outstanding differences between MW and HH. With the corrections included, the comparison with MW is as shown in the last column of Table X. The MW scale is therefore in agreement with the results of the re-reduction of the Harvard data from about the eighth magnitude downward. Above the seventh magnitude the differences are uncertain, either because of the small number of observations included in the re-reduction or because the calculated magnitudes are at the extremity of the scale which they define.

IV. THE DIVERGENCE FOR THE FAINT STARS

The large difference between the Harvard and Mount Wilson results for the faint stars (see Table III above, or, better, Table IX, *Mt. Wilson Contr.*, No. 97) is to be ascribed to two circumstances: (*a*) the neglect of the distance-correction in reducing the MW plates which enter into the Harvard discussion; (*b*) the application of a correction to the majority of these plates to allow for the order of exposure.

a) *Effect of Distance Correction*

When the Mount Wilson plates were reduced by Miss Leavitt the values of the distance-correction were not yet available. In

consequence, an attempt was made to avoid the difficulty by including only stars which were within a limited distance of the center of the plate (L, 140). Subsequently some of the plates were re-reduced by Miss Leavitt, using values of the correction which in the meantime had been determined at Mount Wilson, but without finding any important modification of the results (*loc. cit.*).

The amount of the correction is, however, not negligible. The matter is most easily illustrated in connection with Group 18, as in other particulars these plates were similarly treated in both the Harvard and Mount Wilson reductions. The values for this group given by Miss Leavitt on p. 189 are referred to the zero point of the provisional magnitudes on p. 141 (L, 180); but it is convenient to reduce them to the zero-point defined by the Mount Wilson magnitudes between 10 and 15. When this has been done the difference between Group 18 and the corresponding portion of the Mount Wilson scale will be of the form

$$\mathrm{MW}-(18)_{\mathrm{H}}=\mathrm{MW}-(18)+\mathrm{D.C.}$$

in which $(18)_{\mathrm{H}}$ represents Miss Leavitt's values for Group 18 corrected for zero-point, while (18) is what would have been obtained had the distance-correction been applied. The subtraction of the term D.C. will therefore leave MW$-$(18), which represents the difference between MW and the Harvard reduction after revision for distance-error.

The zero-point correction is found to be 0.39 mag. and its application to the magnitudes in L, 189, gives the quantities in the second column of Table XI. Values in parentheses are relatively uncertain. The deviations from MW are in the third column; it is seen at a glance that these are very similar to the distance-corrections in the following column, which have been derived from the Mount Wilson reduction tables. The differences between MW and $(18)_{\mathrm{H}}$ corrected for D.C. (in the last column) have a mean value of -0.04 magnitude; but, it is found from Table XII, *Mt. Wilson Contr.*, No. 97, that the weighted systematic deviation of the Mount Wilson reduction of Group 18 (Plates 196, 200, 204) from the final Mount Wilson scale is -0.03 magnitude. The neglected distance-correction, therefore, completely accounts for the difference between

the Harvard and Mount Wilson reductions. Similar differences also affect the plates comprising Groups 19 and 20, but it does not seem necessary to make a detailed comparison. The effect upon

TABLE XI

EFFECT OF DISTANCE CORRECTION

Star	Gr. 18+0.39	$MW-(18)_H$	D.C.	MW−(18)
31	16.35	+ 6	+ 7	− 1
15*s*	16.59	− 2	+ 2	− 4
32	16.89	−13	0	−13
16*s*	17.06	−20	+ 2	−22
33	17.26	−20	− 3	−17
17*s*	17.39	−20	−25	+ 5
34	17.43	−19	−12	− 7
35	17.64	− 1	−21	+20
36	17.86	− 8	−23	+15
37	18.21	−20	−17	− 3
18*s*	(18.21)	(−27)	−30	(+ 3)
38	18.44	−24	−26	+ 2
19*s*	18.62	−46	−46	0
39	18.67	− 9	−28	+19
20*s*	(19.06)	(−46)	−11	(−35)
21*s*	18.98	−32	−34	+ 2
22*s*	18.93	−18	−15	− 3
23*s*	(19.32)	(−62)	−45	(−17)
24*s*	(19.25)	(−37)	−25	(−12)
40	19.09	−22	−12	−10
25*s*	19.34	−50	−16	−34
41	19.32	−30	−12	−18
Means		−19	−15	− 4

the scale begins to be appreciable at about the sixteenth magnitude, and gradually increases to a maximum of about 0.4 magnitude for the faintest and least favorably situated stars.

b) Correction for Order of Exposure

From the data used by Miss Leavitt it appears that when several exposures are made upon the same plate, the first and last being short and equal, the images of the first exposure are generally brighter than those of the last. The mean difference she finds to be about a quarter of a magnitude.

The question thus raised is of great importance for the reduction of plates involving successive exposures, for it has a direct and important effect upon the scale. A symmetrical arrangement of

the exposures, or, failing this, a correction depending upon the order of exposure, immediately suggests itself as a means of eliminating the disturbance.

This, however, assumes that the phenomenon develops proportionally to the time, which in the absence of more definite information is a perfectly natural supposition. Miss Leavitt has followed this procedure, and accordingly plates MW 196, 200, 204 (Group 18), for which the arrangement of exposures was symmetrical, received no correction. The plates of Groups 19 and 20 (MW 230, 232, 235, and MW 310, 312, 313), however, were not symmetrical in their arrangement, and have therefore been corrected on the basis of systematic differences derived from the short preliminary and supplementary exposures impressed on each plate.

The values of the measured differences between first and last exposures and the fractional part applied to the images of each of the principal exposures are shown on pp. 122 and 124 of her memoir. As the order of the principal exposures on all of the plates in question was the same, namely, full aperture followed by reduced aperture, the correction always modifies the results in the same direction; the difference in the images with full and reduced aperture is diminished, so that in calculating the scale the faint magnitudes become relatively fainter than they otherwise would have been.

No extensive calculation is required to show how the correction has modified the results from Groups 19 and 20, for a direct indication is afforded by the details in Miss Leavitt's discussion. It was found that the short supplementary exposure on one of the plates (MW 310, H 285) in Group 20 could not be measured, and in consequence no correction was applied (L, 182). The other plates (MW 312, 313; H 286, 287), however, were corrected as usual. Turning now to p. 184 of Miss Leavitt's memoir, it is seen at once that for the faint stars there is a large difference between the mean result for the last two plates and that for the first. For convenience, the deviations of the two scales thus defined from the mean for Group 20 are given in the third and fourth columns of Table XII. The difference between these two series of residuals, which appears in the fifth column, expresses very approximately the effect of the correction.

That the systematic difference thus exhibited is not inherent in the plates themselves appears at once upon referring to Table XII of *Mt. Wilson Contr.*, No. 97, which gives for the Mount Wilson

TABLE XII

CORRECTION FOR ORDER OF EXPOSURE

Star	MW Mag.	Pl. 310−Gr. 20	½(312+313)−Gr. 20	Pl. 310−½(312+313)	Gr. 18−Gr. 20	Gr. 18−Pl. 310	Gr. 18−½(312+313)
31......	16.41	−20	+8	−28	−37	−17	−45
15s......	16.57	−21	+6	−27	−29	−8	−35
32......	16.76	−12	+5	−17	−33	−21	−38
16s......	16.86	−6	+2	−8	−23	−17	−25
33......	17.06	−12	+4	−16	−19	−7	−23
17s......	17.19	−20	+13	−33	−22	−2	−35
34......	17.24	−28	+14	−42	−36	−8	−50
35......	17.63	−16	+9	−25	−39	−23	−48
36......	17.78	−26	+12	−38	−43	−17	−55
37......	18.01	−20	+10	−30	−23	−3	−33
18s......	17.94	−20	+14	−34	(−10)	(+10)	(−24)
38......	18.20	−50	+25	−75	−49	+1	−74
19s......	18.16	−33	+8	−41	−57	−24	−65
39......	18.58	−50	+33	−83	−62	−12	−95
20s......	18.60	−40	+27	−67	(−28)	(+12)	(−55)
21s......	18.66	−38	+19	−57	−67	−29	−86
22s......	18.75	−11	+8	−19	−87	−76	−95
24s......	18.88	+7	−7	+14	(−36)	(−43)	(−29)
25s......	18.84	−38	+38	−76	−50	−12	−88

reduction (in which none of the plates was corrected) the deviations of individual plates from the mean Mount Wilson scale. For the region covered by the table above we find as a weighted mean:

$$\text{MW reduction: Pl. } 310-\tfrac{1}{2}\text{ (Pl. } 312+313)=+0.02 \text{ mag.}$$

When similarly treated, therefore, the three plates give closely accordant results. As a matter of fact, the effect of the correction is about a tenth of a magnitude greater than the differences shown by the fifth column of Table XII, since the mean distance of the stars from the center of the plate is about 5 mm greater for MW 310 than for 312 and 313; and since none of the Harvard measures were corrected for distance, the magnitudes for MW 310 are relatively too faint by approximately the amount mentioned.

It is of interest further to compare Miss Leavitt's results for MW 310 with those for Group 18. This is at once accomplished by combining the third and sixth columns of Table XII, the results for

the latter column having been derived from L, 189. The differences in the seventh column reveal a relatively small systematic effect. In other words, the uncorrected plate MW 310, which presumably is affected by the phenomenon under discussion since all of the other Mount Wilson plates of unsymmetrical arrangement seem to be so affected, gives results agreeing closely with those for Group 18 from which the systematic effect has supposedly been eliminated by a symmetrical arrangement of the exposures. On the other hand, plates MW 312 and 313, which have received correction, differ widely in their results from those of Group 18 (last column Table XII).

This immediately raises a suspicion as to the validity of the assumption upon which the above-described procedure was based. The matter can be tested further by means of the Mount Wilson results for individual plates, part of which appear in Table XII of *Mt. Wilson Contr.*, No. 97. Of the plates there listed Nos. 230, 232, 235, 310, 312, 313, and 314, on the basis of the procedure followed by Miss Leavitt, would require correction for the order of exposure. None of the others, and none of the fifteen plates of shorter exposure which were also used in deriving the MW scale, would need such correction, either because of a symmetrical arrangement of the data or because of the minuteness of the differences between the first and last exposures (in the case of Nos. 769 and 808). A comparison of the scales from the two groups of plates should therefore show at once the result of having neglected the correction in the case of the questionable series. Moreover, the difference in the two scales should be a reliable indication of the effect produced, for the amount of the material is such as to reduce to a minimum the errors arising from other sources.

From Table XII, *Mt. Wilson Contr.*, No. 97, we find the weighted deviations of the mean scale for Plates 230, 232, etc., from the final Mount Wilson scale to be as shown in Table XIII. Since the weight of the results from the plates of symmetrical arrangement is considerably in excess of that from Nos. 230, 232, etc., the scale difference for the two groups is somewhat less than twice the systematic difference in Table XIII; but the result thus attained is within the limit of error which may arise from other sources, and we are led

again to the conclusion expressed above, namely, that the assumption upon which the whole procedure is based is unjustifiable.

TABLE XIII

MW—(Pl. 230, 232, etc.)

MW Mag.	Syst. Dev.	Wt.	MW Mag.	Syst. Dev.	Wt.
11.1........	−0.005	30	16.1........	−0.018	154
12.2........	+ .053	39	16.6........	− .029	186
13.2........	+ .031	52	17.1........	− .005	159
13.7........	+ .015	68	17.6........	+ .016	233
14.1........	− .028	61	18.1........	+ .016	241
14.6........	− .001	134	18.6........	+ .040	358
15.1........	− .024	174	19.1........	+0.056	77
15.6........	−0.019	127			

Moreover, we may say with some definiteness that the questionable group of plates requires no appreciable correction whatever in order to arrive at a correct scale (excluding unsuspected disturbances which may arise from other sources). Both our own measures and those by Miss Leavitt and Miss Leland show that in the main there is no sensible difference between the first and last exposures upon plates MW 196, 200, and 204. Plates 769 and 808 which were used only for the Mount Wilson scale give a similar result. The mean scale from these five plates should therefore be free from any influence due to the phenomenon under discussion; but this scale we find from Table XII, *Mt. Wilson Contr.*, No. 97, to be practically identical with that derived without correction from the plates which do show differences between initial and final exposures. Apparently, therefore, the principal exposures on these plates, which are the ones used in deriving the scale, contain little or nothing of the systematic difference that is revealed when the short preliminary and final exposures are compared.

The phenomenon is obviously photographic in origin, and Mees has suggested,[1] as the most probable explanation, that it is due to a depression of the sensitiveness of the plate through the absorption of water-vapor upon exposure to the air. No data are available as to the time required for a condition of equilibrium to be established, but it is perhaps not inconceivable that the major part of the change

[1] *Astrophysical Journal*, **40**, 236, 1914.

should occur within a comparatively short interval after the beginning of the exposure. It might thus easily happen that only the first of a series of equal exposures would be markedly different from the others; and if the exposures were long the difference might be more or less completely obscured.

The question will be discussed further at another time; but one point requires mention before the subject is dismissed, and that is the apparent susceptibility of the measures used in this part of the discussion to systematic error. This is well illustrated by the results for different observers and different scales given in L, 122, and again, by the comparison of these results with our own for the same plates as measured by Miss High and Miss Richmond.

A striking result is the fact that measures made here agree in fixing a much smaller value for the mean difference between the initial and final exposures than that found by Miss Leavitt; but most extraordinary is the circumstance that we find the variation of the difference with size of image to be entirely different in character from that illustrated in Miss Leavitt's memoir (Plate 3, Fig. 1). For the Mount Wilson plates she finds in general that the difference is a maximum for the faintest images, while for these we usually find no difference at all.

Had we corrected the Mount Wilson plates, using our own measures, the scale for the six or seven plates thus modified would have been deflected by rather less than half the amount entering into the Harvard results. The matter would be disconcerting were it not pretty clear that it should not enter into the discussion at all, and were it not further clear that, when similarly treated, Miss Leavitt's measures of the more essential portion of the data and our own give practically identical results for the scale.

The preceding discussion does not extend the comparison with the Harvard results below the nineteenth magnitude; it is unnecessary, however, to carry the matter further. The Harvard magnitudes of the faintest stars depend upon an extrapolation of the scale for the region just considered, and it is evident that the divergence which has entered in the manner indicated must produce even greater differences for still fainter objects. These are quite sufficient to account for the difference in the limiting magni-

tudes reached in the two investigations—21 for Harvard and 20 for Mount Wilson.

SUMMARY

1. The Mount Wilson color-indices of the Polar Sequence stars afford the possibility of investigating the influence of color upon the results obtained with the various instruments used in deriving the Harvard photographic scale. It is found that corrections of a few hundredths of a magnitude (4th col., Table III) are required to reduce this scale (that of *H.C.*, No. 170+0.08 mag.) to a homogeneous color-system (HH, Table III).

2. The comparison of the Harvard Homogeneous Scale (HH) with MW reveals a color-equation with a coefficient of 0.06. Including the scale-divergence for the bright stars, we have to the sixteenth magnitude, approximately

$$\mathrm{MW}-\mathrm{HH}=+0.061\,(\mathrm{HH}-6.0)+0.06\,\mathrm{C}$$

in which C is the color-index, and in which, further, the first term is constant and equal to +0.24 magnitude from the tenth magnitude onward. The allowance for color has therefore appreciably diminished the divergence between the sixth and the tenth magnitudes given by the earlier comparisons. For the faint stars there remains a large difference between the two scales, which at the twentieth magnitude (MW) amounts to about one magnitude.

3. The acceptance of the HH magnitudes between 10 and 15 as an accurately established scale makes it possible to re-reduce much of the Harvard data for the bright stars by methods which are free from various uncertainties that necessarily affect the original reduction. It is thus found that the HH magnitudes apparently require small corrections which improve the agreement with MW and extend the region of parallelism for the two scales upward from the tenth to the eighth magnitude (6th and 9th cols., Table X). The remaining discrepancy of a quarter of a magnitude is thus thrown upon the stars which are brighter than the eighth magnitude.

4. The divergence for the faint stars is due to the neglect of the distance-correction in reducing the Mount Wilson plates used for the Harvard scale, and to the application of a correction intended

to remove the influence of the systematic difference sometimes affecting initial and final exposures on photometric plates. With proper allowance for these differences in procedure, the Harvard scale becomes parallel with that of Mount Wilson in the region of the faint stars.

5. The photographic phenomenon which shows itself as a systematic difference between first and last exposures seems for the most part to occur within a short interval after the beginning of the first exposure, for the principal exposures, on the Mount Wilson plates at least, require no correction in order that they may give results accordant with those from plates which do not show the effect at all.

Mount Wilson Solar Observatory
February 9, 1915

MISCELLANEOUS NOTES ON VARIABLE STARS[1]

By HARLOW SHAPLEY

The following collection of notes and data on subjects related almost exclusively to variable stars represents the results of short or partial investigations that have been undertaken during the last two years. A part of the observational work involved was done at the Princeton University Observatory, but the reduction and discussion of the observations and the statistical and other computations were made at Mount Wilson. The incomplete series of observations on eclipsing variables are published now because there will be no immediate opportunity to continue the work.

The contents of the several notes are as follows:

1. Comparison of the observed solar darkening with the assumed stellar darkening—an inquiry into the applicability of the formula $J=J_0\ (1-x+x\ \cos\ \gamma)$ to the representation of the distribution of light over the disk of the sun. The investigation is based on published and unpublished observations from the Astrophysical Observatory of the Smithsonian Institution.

2. Observations of a minimum of the F-type eclipsing star U Pegasi and the derivation of new light-elements.

3. Photometric measures of *o* Persei for the purpose of testing its light-variability.

4. Photometric observations of R Canis Majoris.

5. The visual range of AE Cygni, with a provisional solution for uniform orbital elements.

6. The relation between spectrum and length of period for close double stars, including eclipsing variables and spectroscopic binaries of the non-Cepheid type.

7. On the number of naked-eye variable stars of different classes.

The manuscript data concerning recent measures of the distribution of brightness over the disk of the sun were kindly furnished

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 99.

by Mr. Abbot. The sixth and seventh notes were prepared and written by Mrs. Shapley.

I. ON DARKENING TOWARD THE LIMB OF THE SUN

In the study of the light-curves and orbital elements of eclipsing binaries the nature of the distribution of brightness over the apparent stellar surfaces has been found to be of paramount importance. The observed darkening toward the limb of the sun was taken as a basis for the assumption as to the general character of stellar darkening. Since the adoption of an empirical cosine formula to represent the diminution of light from center to limb, the actual existence of darkening for stars of various spectral types has been definitely demonstrated;[1] but the suitability of this particular formula remains undetermined, and the dependence of the darkening coefficient on wave-length and spectral type is as yet unknown.

In the case of the sun the applicability of the adopted formula, and also the dependence of the coefficient on the mean wave-length of the light used in obtaining the light-curve, can be directly studied with the aid of the bolometric observations of the Astrophysical Observatory of the Smithsonian Institution. For stars of other spectral types, however, we can now only speculate as to how the law of darkening may differ and what the degree of darkening may be for the light of different wave-lengths.[2] There is perhaps an indication that it is greater for the bluer stars, and a refined study of appropriate light-curves will doubtless contribute something to the solution of the problem.

A comparison of the bolometric results with the formula has not been made heretofore, and in the present note a brief discussion will be given of the diagrams, Figs. 1 and 2, in which such a comparison is presented.

Letting J_0 be the value of the apparent surface brightness J at the center of the disk, the assumed relation between J and the

[1] *Contributions from the Princeton University Observatory*, No. 3, pp. 106–110, 1915.

[2] Relative to the uncertainty in orbital computations arising from the present indefinite state of the darkening-at-the-limb problem see the above-cited work, chap. iii, and *Astrophysical Journal*, **40**, 219, 1914.

apparent distance from the center is $J/J_0 = 1 - x + x \cos \gamma$, where the darkening coefficient is x and γ is the angle between the line

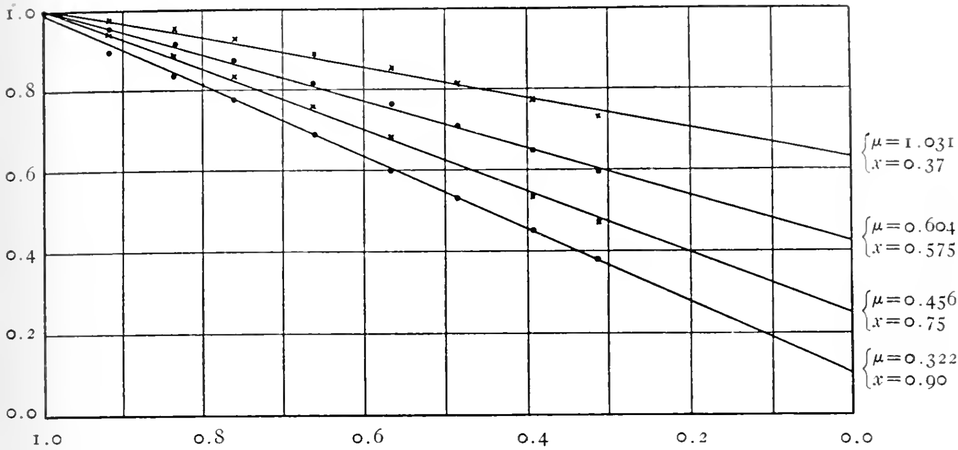

FIG. 1.—Solar darkening in 1907
Abscissae: cos γ; Ordinates: J/J_0

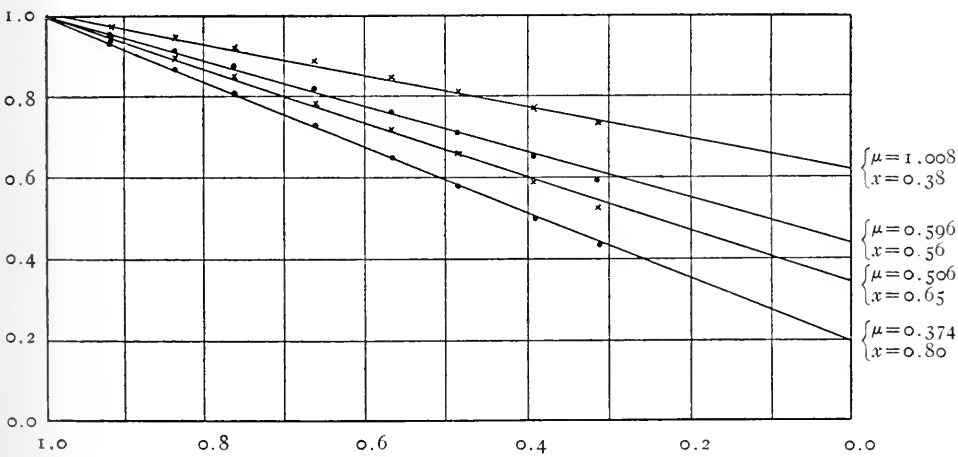

FIG. 2.—Solar darkening in 1913
Abscissae: cos γ; Ordinates: J/J_0

of sight and the surface normal. The means of the bolometric measures made at Washington in the year 1907 (sun-spot maximum)

are given in *Annals of the Astrophysical Observatory of the Smithsonian Institution*, **3**, 157, 1913, and an accompanying diagram represents sin γ plotted against J/J_0 for several different wave-lengths. When we plot the measures against cos γ, as I have done for four representative wave-lengths in Fig. 1, the observed points should lie on a straight line if the foregoing formula is sufficient. The bolometric work at Mount Wilson during September, October, and November 1913 (sun-spot minimum) is represented for four wave-lengths in Fig. 2. In both diagrams the mean wave-length of the part of the spectrum used is written opposite the straight line that most nearly satisfies the observations, and the slope of the line, which is the darkening coefficient x, is also given. $1-x$ is the brightness at the limb in terms of the central brightness. The data for $\mu=0.322$ are from photographic results by Schwarzschild and Villiger.[1]

Three results of importance to this inquiry can be deduced from the diagrams:

1. The observed points, though lying on smooth curves, do not define straight lines for any of the wave-lengths of either series, and the deviations are evidently larger than the uncertainties of the observations. Therefore the formula adopted for the stellar investigation does not completely represent the observed solar darkening. The representation is quite satisfactory, however, since the error is generally less than 1 per cent and scarcely exceeds 3 per cent for any wave-length or for any distance from the center up to 95 per cent of the radius (cos $\gamma=0.31$). Beyond this point there is an indication that the brightness may fall off rapidly; but, to quote Abbot's *The Sun*, p. 107, footnote, "There is a tendency of all the data to show a less rapid fall of brightness from 95 to 97 per cent out on the radius than would be expected. This may be due to error." The effect on the light-curve of a variable star of the error in the assumed formula would be entirely negligible (even if we had an exact value of the coefficient) over at least 95 per cent of the curve at minimum. We conclude, therefore, that the adopted cosine law of darkening, though manifestly inexact, is a very good approximation and sufficiently accurate for the

[1] *Astrophysical Journal*, **23**, 284, 1906.

stellar work of the present time. Knowledge of the amount of darkening for a given wave-length and for different spectral types is a more important and immediate need.

2. For the solar spectral type, at least, the value of the darkening coefficient is conspicuously greater for photographic light-curves than for visual—a well-known phenomenon. The average value of x is approximately 0.75 for the mean effective photographic light, and for the mean visual part of the spectrum, about 0.6. This of course does not necessarily mean that the coefficient would be greater for stars of bluer spectral types.

3. For a given wave-length the darkening coefficient decreases with the number of sun-spots, this change being more pronounced for the shorter wave-lengths. Or stated in another way,[1] "there was distinctly less contrast of brightness between the edge and center of the sun's disk in 1913 than in 1907," and the shorter wave-lengths change in contrast more than the longer. This can be shown easily by plotting μ against x for the two series. There are also changes in contrast accompanying the short-period irregular variations of the sun. Apparently, then, our problem may involve a variable darkening coefficient.

2. NEW LIGHT-ELEMENTS FOR U PEGASI

On the basis of the following series of observations made with the polarizing photometer during a single principal minimum of U Pegasi it is possible to make a small but definite correction to the period. The star B.D.$+14°5077$ (7.9), which is about three magnitudes brighter than the variable, was used for the comparisons.

The light-elements of U Pegasi generally adopted at present are those deduced by Roberts[2] from Wendell's observations at the Harvard Observatory:[3]

$$\text{Prin. Min.} = \text{J.D. } 2415021.2367 + 0^{\text{d}}.374784 \text{ E}$$

Apparently a small error exists in the yearly *Vierteljahrsschrift* catalogues since 1912 in giving the light-elements and ephemeris

[1] *Report of the Secretary of the Smithsonian Institution for the Year Ending June 30, 1914*, p. 94.

[2] *Monthly Notices*, **66**, 135, 1906.

[3] *Harvard Annals*, **69**, 53, 1909.

for this star.[1] The initial epoch there reads J.D. 2415021.2469; hence all times are predicted 15 minutes too late, which is a noticeable amount in this case of a nine-hour period.

TABLE I

PRIMARY ECLIPSE OF U PEGASI, OCTOBER 31, 1913

Gr. Helioc. Mean Time	Phase	Magnitude Difference	O−C
			mag.
$14^h\ 3^m$	$-0^h\ 13^m$	3.37	−0.04
14 13	−0 3	3.46	+ .01
14 25	+0 9	3.39	− .04
14 35	+0 19	3.35	− .01
14 46	+0 30	3.31	+ .06
14 59	+0 43	3.17	+ .03
15 19	+1 3	3.00	− .02
15 29	+1 13	2.98	.00
15 39	+1 23	2.87	− .07
15 49	+1 33	2.91	.00
16 1	+1 45	2.87	.00
16 12	+1 56	2.90	+0.04

The corrected heliocentric time of principal eclipse on October 31, 1913, predicted by means of Roberts' elements, is 13^h48^m, G.M.T. The observed time was 14^h16^m, G.M.T., with an uncertainty not exceeding two or three minutes. The difference of 27 minutes represents the accumulation of the error in the period during sixteen years. The accuracy of the elements determined by Roberts is sufficient to leave no doubt as to the number of intervening periods. There were 13,478 revolutions between the date of my observations and the published initial epoch, and about two thousand more between that arbitrary epoch and the middle of the interval over which Wendell's observations of the principal minimum extend. The correction to the period derived from these data is +0.10 seconds, so that the revised value is $0^d.3747852$, with a probable uncertainty of two or three units in the last place. The new heliocentric epoch of primary minimum is

$$\text{J.D. } 2420072.5754 = 1913, \text{ October } 31,\ 13^h48^m.6, \text{ G.M.T.}$$

The phases given in the table above were computed by means of the new elements. The residuals in the last column show the

[1] *Vierteljahrsschrift der Astronomischen Gesellschaft*, **47**, 301, 1902.

agreement of the present short series of measures with the theoretical darkened curve based on Wendell's observations.[1] The representation is quite satisfactory, both as to depth and as to duration of the eclipse, and suggests that no marked change has occurred in the nature of the eclipse during the last fifteen thousand revolutions of the components. The data here available are obviously insufficient, however, to give this last conclusion much weight; but it may be pointed out that such extremely short-period systems as U Pegasi and W Ursae Majoris are deserving of careful and continuous attention from observers, with the object of establishing the presence or absence of sensible perturbations in the length of the period, the range of variation, or the general nature of the light-curve. Both systems are very close, their orbits are apparently circular, their spectral types are F and G, respectively, their components are the densest stellar bodies known, and both possess a high degree of ellipticity. In fact, one-third of the range of light-variation of U Pegasi at principal minimum is attributable to the rotation of the elongated components.

3. PHOTOMETRIC OBSERVATIONS OF *o* PERSEI

The possibility that the spectroscopic binary *o* Persei is also an eclipsing variable has been recognized by several observers, and the constancy of its light has been put to test by Lau,[2] Guthnick,[3] and Hertzsprung.[4] Both Lau and Guthnick announce a variability of the light through a range of 0.35 mag., and the latter finds the time of minimum in agreement with the expectation of eclipse. Hertzsprung, on the other hand, finds no definite evidence of variability, but he points out that none of his observations were made within five hours of the predicted time of principal minimum. Before

[1] *Contributions from the Princeton University Observatory*, No. 3, p. 176, *et passim*, 1915.

[2] *Astronomische Nachrichten*, **196**, 427, 1914.

[3] *Ibid.*, **197**, 303, 1914. Since writing the above, Guthnick's discussion of his preliminary results for this star with the photo-electric photometer have been received (*Veröffentlichungen der Königlichen Sternwarte zu Berlin-Babelsberg*, **1**, No. 1, p. 57, 1914). The results, which are not as yet very definite, suggest a variation of a tenth of a magnitude.

[4] *Astronomische Nachrichten*, **199**, 140, 1914.

learning that the star was under investigation elsewhere the writer had commenced a series of observations with the Princeton polarizing photometer. The results of measures on three nights are given in Table II.

TABLE II

OBSERVED MAGNITUDES OF *o* PERSEI

Date	Gr. Geoc. M.T.	Phase from Super. Conj.	Magnitude Difference	Remarks
			mag.	
1913, Nov. 21 ...	$13^h 31^m$	$+19^h 27^m$	$a-o=+4.01$	
	13 44	+19 40	$a-o=+3.99$	
	13 55	+19 51	$a-o=+4.03$	
Dec. 12 ...	20 9	− 0 12	$b-o=+4.62$	
	20 24	+ 0 3	$b-o=+4.67$	
	20 40	+ 0 19	$a-o=+4.00$	
	20 55	+ 0 34	$a-o=+4.08$	Measure interrupted
	21 18	+ 0 57	$a-o=+3.99$	Star low
Dec. 15 ...	10 26	+62 5	$a-o=+3.90$	Moon
	10 36	+62 15	$a-o=+3.90$	
	10 50	+62 29	$b-a=+0.65$	

The phases were computed with the aid of the spectroscopic elements by Jordan.[1] The comparison stars are a=B.D.+31°644 (8.3), and b=B.D.+31°643 (8.2). Each observation is the mean of 16 comparisons and has a probable error of approximately ±0.03 mag. The fourth observation on December 12 should perhaps be given low weight.

The magnitudes in the table, so far as they go, give no indication of variability, although they were made apparently at the most favorable times. If, however, the orbit which was found by Jordan to be circular should be slightly eccentric, the principal minimum might be displaced sufficiently from the predicted time to render inconclusive the foregoing evidence against variability.

4. PHOTOMETRIC OBSERVATIONS OF R CANIS MAJORIS

The remarkable hump on the light-curve of R Canis Majoris at the end of the principal minimum was measured independently by Professors E. C. Pickering and O. C. Wendell at Harvard more than twenty years ago. The existence of the phenomenon

[1] *Publications of the Allegheny Observatory*, **2**, 63, 1911. The period is 4.41916 days.

at that time seems to be entirely beyond question; but so far as I know there has been no recent observation of the star, and no further investigation of the anomalous feature. With the hope of throwing some light on this peculiarity, a series of observations was undertaken with the Princeton polarizing photometer, but because of the southern declination of the star and the continued unfavorable weather during the short observing season, the work was given up before satisfactory results could be obtained. The observations given below may be of value to other observers, however, not only in showing that if the hump now exists it has perhaps shifted along the curve away from minimum, but also in showing that the light-elements by Chandler do not at present adequately represent the observed times of minima.

The predicted time of eclipse on March 22, 1913, was 15^h32^m, Gr. Hel. M.T. The observed time of mid-eclipse was about half an hour earlier. This difference may not indicate that a correction to the mean period is necessary. The orbit of R Canis Majoris

TABLE III

OBSERVED MAGNITUDES OF R CANIS MAJORIS

Date	Gr. Geoc. M.T.	$a-v$	Date	Gr. Geoc. M.T.	$a-v$
1913		mag.	1913		mag.
Mar. 12	11^h48^m	2.11	Mar. 22	12^h59^m	2.02
	11 57	2.06		13 8	2.04
	12 14	2.06		13 26	1.90
	12 24	2.14		13 36	1.88
	12 40	2.10		13 47	1.88
	12 49	2.10		14 3	1.77
	13 2	2.14		14 13	1.66
	13 11	2.12		14 30	1.52
	13 23	2.09		14 44	1.49
	13 33	2.10		14 54	1.42
	13 43	2.19		15 4	1.37
	13 57	2.18		15 16	1.43
Mar. 22	12 37	2.12		15 30	1.43
	12 50	2.02		15 44	1.56

has an exceptionally high eccentricity for an eclipsing binary;[1] furthermore, the line of apsides is evidently in fairly rapid motion, but with an unknown period.[2] The resulting oscillation in the

[1] *Publications of the Allegheny Observatory*, **3**, 52, 1913.

[2] *Contributions from the Princeton University Observatory*, No. 3, p. 95, 1915.

time of the principal minimum may then easily be of the order of the discrepancy observed. Further investigation of the light-curve is much to be desired, not only to contribute to our knowledge of orbital changes in close binary systems of pronounced eccentricity, but also to elucidate the meaning and the present nature of the hump in the light-curve, which stands out as the most conspicuous unexplained irregularity known in the light-curve of any eclipsing binary.

The comparison star used in the measures above, a=B.D. $-16°1886$ (8.0), is reddish. The last two observations of each night should receive low weight because of the low altitude and trouble with smoke and haze.

The observations on March 22, 1913, indicate that the range is at least a tenth of a magnitude greater than observed by Wendell fourteen years earlier. The results of computations on the photometric orbit and a discussion of them are given in *Contributions from the Princeton University Observatory*, No. 3.

5. NOTE ON THE PROVISIONAL ORBIT OF AE CYGNI

The following series of observations of the faint eclipsing variable AE Cygni are of value chiefly in showing the visual range of variation and in giving one epoch of minimum. They are not conclusive as to the existence of a secondary minimum nor of ellipticity. The comparisons were made with the star a=B.D.$+29°4347$ (8.2). Each observation in Table IV contains 16 settings made with the polarizing photometer.

TABLE IV

OBSERVATIONS OF AE CYGNI

Date	Gr. Geoc. M.T.	$v-a$	Date	Gr. Geoc. M.T.	$v-a$
1912		mag.	1912		mag.
June 10..........	$16^h 53^m$	+3.04	Nov. 3..........	$15^h 15^m$	+2.40
	17 6	3.17		15 29	2.42
	17 23	3.16		15 48	2.40
	17 38	3.21		16 1	2.44
			1913		
Nov. 3..........	14 16	2.54	Jan. 1..........	11 11	2.39
	14 31	2.42		11 25	2.35
	14 48	2.46		11 47	2.46
	15 1	2.42		12 2	2.40

The light-elements given by Williams[1] represent the measures printed in Table IV with sufficient accuracy. His light-curve, however, which is based on 83 visual observations, presents unusual difficulties in the derivation of even approximate orbital elements. In order to investigate the system further my observations were undertaken, but the faintness of the star and the inconvenient length of the period ($23^h 15^m.6$) have prevented decisive results from being obtained. The range of variation according to my measures is 0.77 mag. With this value the scale-readings given by Williams were converted into magnitudes and the resulting light-curve investigated. If the period is as given above, the provisional orbital elements are:

Ratio of radii	=0.75
Inclination of orbit	=85°
Radius of orbit	=1.00
Radius of larger star	=0.45
Light of larger star	=0.50

But in this case a secondary minimum of three-tenths of a magnitude would be required, the existence of which is not verified by my observations; moreover, the components would be so close together that considerable elongation would be expected and the range as given above would then be illusory for orbital computations.

It seems more probable that the period is double the value given by Williams, that the stars are not markedly ellipsoidal, and that the alternate minima are probably of unequal depth. As a consequence, the components would be found to be of nearly equal dimensions, much smaller relative to the size of the orbit than given above, and the mean density of the system would be of the order of two-tenths that of the sun. If the shorter value of the period is correct, the mean density is one-half as large. The spectral type is unknown.

6. ON THE PERIODS AND SPECTRA OF CLOSE BINARY STARS

The following study has been made to supplement the recent work of Wicksell on the frequency of the periods of spectroscopic

[1] *Astronomische Nachrichten*, **184**, 97, 1910.

binaries,[1] and to determine whether the conclusions reached in his paper can be considered more than an apparent result depending on selection. He finds two distinct maxima in the frequency-curves for all spectral types and attempts to explain this on the assumption that in spectroscopic double stars the groups of long and short periods depend on two different principles or conditions of origin. He suggests, however, the possible insufficiency of his data.

Since there is essentially no difference between spectroscopic and eclipsing binaries, except that the latter are limited in the possible values of their orbital inclination, there is no reason why the data for the two classes of stars should not be combined in a study of this kind. Accordingly a card catalogue of eclipsing variables was made, which contains over 200 entries, and the 121 stars for which both period and spectral type are known form, together with Wicksell's data, the basis of this discussion. From Wicksell's list all those spectroscopic binaries which are known also to be eclipsing variables were removed; 14 spectroscopic binaries not in his list, but whose periods and spectral types are available, were added; and for one star, π_5 Orionis, a later value of the period was substituted. All Cepheid variables were excluded, since it is not certain that they are binary systems; hence four stars not called Cepheids by Wicksell were dropped from his list—β Cephei and α Ursae Minoris, two known Cepheids, and β Canis Majoris and λ Andromedae, whose orbits suggest that they also may belong to this class. A separate study was then made (1) of the eclipsing variables, (2) of the spectroscopic binaries not also known to be eclipsing binaries, and (3) of both the first and second groups combined.

Table V shows the total number of eclipsing and spectroscopic binaries of each spectral type in equal intervals of the logarithm of the period. Two Ma stars and one of type Oe5 were not considered.

Frequency-curves, similar to Wicksell's, were drawn for each spectral type in each of the three above-named groups, i.e., eclipsing binaries, spectroscopic binaries, and the total of both. Curves were

[1] *Arkiv för Matematik, Astronomi och Fysik*, **10**, No. 6, 1914.

also drawn for each group, using all the stars regardless of spectral type, and these are reproduced in the accompanying diagrams.

The supposed secondary maximum is found to occur definitely only in the case of the B-type stars in the spectroscopic group; and in that group it is due solely to six long-period stars. If, as shown by the dotted lines in the diagrams, all B-type stars are omitted, the phenomenon of the two maxima completely disappears. The same result is obtained by omitting only the six B stars of long period. These anomalous systems are: κ Velorum, $116^{d}_{.}65$; ϕ Persei, $126^{d}_{.}6$; ν Orionis, $131^{d}_{.}3$; ζ Tauri, 138^{d}; π Andromedae, $143^{d}_{.}67$; and μ Sagittarii, $180^{d}_{.}2$. ϕ Persei and μ Sagittarii are classified as having peculiar spectra. Evidently then the real problem lies in explaining the spectra or periods of these six stars. The next longest period among the B's is 31 days.

TABLE V

LOGARITHM OF PERIOD AND SPECTRAL TYPE

Spectrum	−0.8 to −0.4	−0.4 to 0.0	0.0 to 0.4	0.4 to 0.8	0.8 to 1.2	1.2 to 1.6	1.6 to 2.0	2.0 to 2.4	2.4 to 2.8	2.8 to 3.2	3.2 to 3.6	3.6 to 4.0	Total No. of Binaries
B..........	....	....	9	16	10	6	....	6	....	....	....	....	47
A..........	....	9	26	40	14	9	3	2	....	1	1	....	105
F..........	1	3	3	8	3	....	3	1	2	....	1	2	27
G..........	1	....	....	2	2	2	1	2	2	3	....	....	15
K..........	....	....	....	....	....	2	....	2	1	....	....	....	5
Total ..	2	12	38	66	29	19	7	13	5	4	2	2	199
F-G-K	2	3	3	10	5	4	4	5	5	3	1	2	

Thus, after more than doubling the data for close binary systems, it appears that the secondary maximum in length of period does not exist, although there are slight indications of it in some of the curves for the separate spectral types. These, however, disappear in the totals except for the six stars mentioned. It is found also that the maximum of all the frequency-curves falls between the values 0.4 and 0.8 for the logarithm of the period, that is, for the periods between approximately 2.5 and 6 days. The B-type stars seem to have a comparatively shorter range in length of period than any of the others (except the K stars, for which the data are too meager to justify any conclusions), namely, 1.45 to

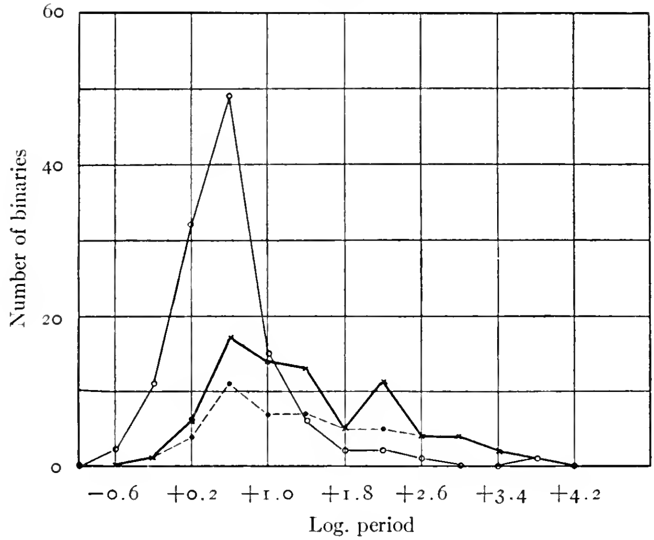

FIG. 3.—Frequency-curves: eclipsing variables, light line; spectroscopic binaries, heavy line; spectroscopic binaries excluding B-type spectra, broken line.

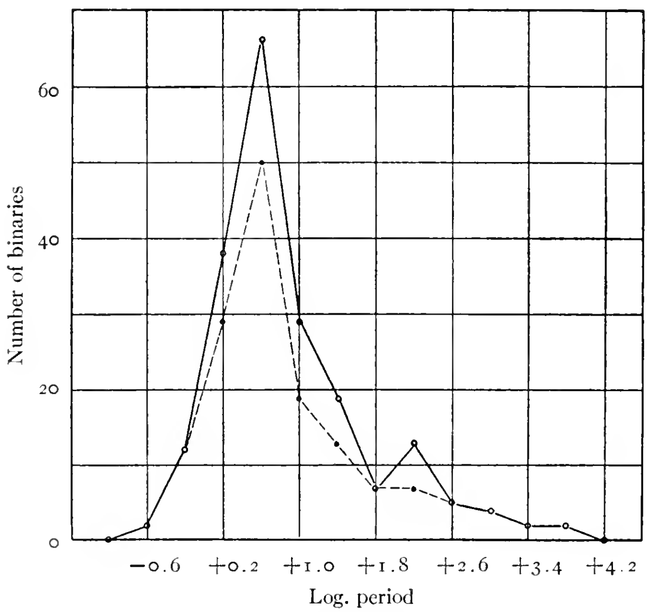

FIG. 4.—Frequency-curve for eclipsing and spectroscopic binaries combined (broken line excludes B-type spectra).

180.2 days; or, without the stars that may be anomolous, 1.45 to 31 days. For the systems with second-type spectra, in which the F's predominate, the range is the greatest, being 0.33 to 9905 days. It is of interest to note that one-third of the second-type systems have periods greater than 180 days and one-seventh shorter than 1.45 days, the outside limits given above for the binaries with B-type spectra.

7. ON THE NUMBER OF NAKED-EYE VARIABLE STARS

As a result of his search for variable stars in globular clusters, Bailey found that about 2.5 per cent of all the stars examined show distinct light-variation; this percentage was compared with the number of variables among the naked-eye stars, which he placed at 1 per cent.[1] Since that study was made the number of known variable stars has considerably increased. In order to get an idea of the percentage of naked-eye stars now known to be variable, and to see how they are distributed in the different variable star classes for each interval of magnitude, the data in Table VI were collected.

TABLE VI

Magnitude	Long Period	Short Period	Eclipsing	Mis-cellaneous	Total Variables	Total Stars	Percentage Variable
< 1.0 ..	0	0	0	5*	5	12	17 per cent*
1.0 to 1.9 ..	0	0	1	1	2	28	7
2.0 to 2.9 ..	1	1	5	1	8	105	8
3.0 to 3.9 ..	3	6	4	7	20	275	7
4.0 to 4.9 ..	5	4	4	9	22	750	3
5.0 to 6.0 ..	18	7	4	20	49	2160	2
Total ..	27	18	18	43	106	3330	3

*Three of the five variables of this magnitude are Novae, and, as they are now from the ninth to the twelfth magnitude in brightness, they are not included in the percentage.

The second, third, fourth, and fifth columns give the number of variables belonging to the different classes named, whose brightness at maximum light corresponds to the magnitude tabulated in the first column. In the class "Miscellaneous" are included variables with unknown or irregular periods and the Novae. Column six contains the total number of variables, and seven the total

[1] *Harvard Annals*, **38**, 1, 1902.

number of all stars, while the final column gives the percentage of variables in each magnitude division. It is seen that 3 per cent of all stars visible to the naked eye are known to vary in light.

In collecting this material the many bright stars recently suspected of small variation by Lau[1] and Guthnick[2] have not been considered, although many of them will probably be admitted soon to the lists of known variables. Had they been included the total percentage would be increased from three to more than five.

Mount Wilson Solar Observatory
February 1915

[1] *Astronomische Nachrichten*, **196**, 427, 1914.

[2] *Veröffentlichungen der Königlichen Sternwarte zu Berlin-Babelsberg*, **1**, No. 1, 1914; *Astronomische Nachrichten*, **191**, 169, 1912.

SOME ORBITAL CHARACTERISTICS OF THE CEPHEID-GEMINID VARIABLES AND A SUGGESTED EXPLANATION OF THE CAUSE OF THEIR LIGHT-VARIATIONS

By C. D. PERRINE

As one result of the investigation of the peculiar distribution of the Cepheid-Geminid variables, and having in mind some of their other peculiarities, I was led to examine the orbits which had been computed. Several seemingly well-marked and suggestive characteristics appeared, in addition to the small values of $a \sin i$ and $\frac{m_1^3 \sin^3 i}{(m+m_1)^2}$ to which Campbell refers.[1] These are: (1) generally large orbital eccentricities; (2) considerable resemblance in ω; (3) considerable uniformity in K. To these may be added: (4) very small, and sensibly common, proper motions; (5) the well-known fact that these stars all belong to classes F and G; and (6) their strong preference for the Milky Way. The data above referred to are brought together in Table I.

There appears to be some relation between the eccentricities and the angles of periastron as shown by Table II.

Why the first four do not agree with the others more closely is not clear. In these orbits (Table II) the larger the eccentricity the more nearly in general the angle ω approaches 90°.

The tendency of the last nine of the stars of Table II to have their angles of periastron near to 90°, or, in other words, the major axes of their orbits near to the line of sight in at least one plane, is undoubted. It may be that this is a preference of the plane of their orbits for the Milky Way. With a better knowledge of the distance and mass of the Milky Way as well as of the stars, investigation of this point might be very fruitful.

It may be noted in passing that in over two-thirds of all of the spectroscopic orbits available to date the value of ω lies between

[1] *Lick Observatory Bulletin*, No. 181, **6**, 51, 1910.

TABLE I

H.R.	Mag. Max.	Star	α 1900	δ 1900	P	Proper Motions* α	Proper Motions* δ	ω	e	K	$\frac{m_1^3 \sin^3 i}{(m+m_1)^2}$	$a \sin i$	V
										km		km	km
	7.2	SZ Tauri	$4^h 31^m.4$	$+18° 20'$	$3^d.15$	$+^s.0066$	$-''.012$	$76°.7$	0.24	10.9	0.0004	460,000	−15.2
2332....	5.0	RT Aurigae	6 22.1	+30 34	3.73	− 5	− 23	95.0	.37	18.0	.0018	856,500	+12.2
2650....	3.7	ζ Geminorum	6 58.2	+20 43	10.15	− 3	− 8	333.0	.22	13.2	.0023	1,797,800	− 4.7
6616....	4.0	X Sagittarii	17 41.3	−27 48	7.01	− 4	− 22	93.6	.40	15.2	.0016	1,334,000	− 3.2
6661....	5.8	Y Ophiuchi	17 47.3	− 6 7	17.12	+ 17	− 30	201.7	.16	7.7	.0011	1,999,000	+10.8
6742....	4.8	W Sagittarii	17 58.6	−29 35	7.60	+ 7	− 12	70.0	.32	19.5	.0050	1,930,000	−18.8
6863....	5.8	Y Sagittarii	18 15.5	−18 54	5.77	+ 5	− 11	32.0	.16	19.0	.0040	1,485,000	+16.8
7518....	6.7	SU Cygni	19 40.8	+29 1	3.84	....	....	346	.21±	25 ±	.0058±	1,350,000±	−15.4
7570....	3.5	η Aquilae	19 47.4	+ 0 45	7.18	+ 5	− 9	68.9	.49	20.6	.0043	1,773,000	+ 1.0
7609....	5.6	S Sagittae	19 51.5	+16 22	8.38	+ 2	− 3	70±	.35±	19 ±	.0049±	2,000,000	+ 4.4
7988....	5.5	T Vulpeculae	20 47.2	+27 52	4.44	+ 5	− 13	111.0	.43	17.6	.0018	969,180	+14.7
8571....	5.4	δ Cephei†	22 25.4	+57 54	5.37	+ 15	+ 3	85.4	.48	19.7	.0028	1,270,000	+12±
	7.0	RR Lyrae	19 22	+42 6	0.567	....	....	96.85	0.27	22.2	0.0006	166,500	−50.4

* All of the proper motions except for SZ Tauri, Y Ophiuchi, SU Cygni, and RR Lyrae are from the *P.G.C.* of Boss. The proper motion of SZ Tauri is from the *A.G. Berlin* catalogue, and that of Y Ophiuchi is deduced from a comparison of *Weisse's Bessel* and *A.G. Wien-Ottakring*.

† The visual magnitude of δ Cephei is 3.7.

0° and 180°. This condition seems to be independent of type, eccentricity, or region of sky. It seems reasonable to expect that small eccentricities may lead to comparatively large uncertainties in the angle ω, but it is doubted if that accounts for the few cases in Table II which differ from the majority.

TABLE II

H.R.	Star	e	ω
6616	Y Ophiuchi	0.16	202°
6863	Y Sagittarii	.16	32
7518	SU Cygni	.21	346
2650	ζ Geminorum	.22	333
	SZ Tauri	.24	77
	RR Lyrae	.27	97
6742	W Sagittarii	.32	70
7609	S Sagittae	.35	70
2332	RT Aurigae	.37	95
6616	X Sagittarii	.40	94
7988	T Vulpeculae	.43	111
8571	δ Cephei	.48	85
7570	η Aquilae	0.49	69

There is another possible explanation, however, viz., that some force, probably the gravitational attraction of the Milky Way, has tended to draw the axes of these orbits into its own plane. These stars are in two groups, three being in the region of the Milky Way not far from the solar antapex and the remaining ten in a group in the Milky Way near the apex. The mean residual velocity for the three stars near the antapex is -2.6 km and of the nine stars near the apex, $+2.5$ km.[1]

There appears to be some connection with magnitude, four stars from magnitude 3.5 to 4 (mean mag. 3.7) having an average radial motion of 5 km, while the remaining eight from magnitude 4.8 to 7.2 (mean mag. 5.8) give 14 km. These results are very consistent among themselves and lead to some confidence that the real velocities of the fainter stars of this class are greater than those of the brighter ones.[2] The possession of so many similar

[1] The abnormally high velocity of RR Lyrae was not used in these velocity results.

[2] Note added February 5, 1915. Subsequent investigation has shown that in the stars of class B also, the inherent velocity is a function of the magnitude.

characteristics indicates a close relationship of some kind and makes the Cepheid group an unusually interesting one.

Does this relationship extend back as far as their origin or is it simply selection, perhaps by the influence of the Milky Way, since they appear to be closely related to it? Can their unique variations in brightness be due to any of the peculiar characteristics of their orbits? It would seem that eccentricity combined with small orbital dimensions and small masses of the secondaries must be largely responsible for it.

The few cases of F- and G-type stars, other than the Cepheid and Geminid variables, with similar relative masses of the secondaries and orbital dimensions, have small eccentricities and show no variation in brightness.

The first suspicion which arises, especially as these stars are all approximately of the age of our sun, is whether they may not belong to a stream of which the sun is a member. This is negatived upon investigation by the fact that their radial velocities differ widely, not only in amount, but also in sign. The undoubtedly great distances of these stars indicate considerable masses for the primaries. On the other hand, the companions appear to be relatively small, conditions perhaps conducive to high eccentricity.

The considerable uniformity in relative masses of the secondaries, a probable similarity in masses of the primaries judging from their magnitudes, similarity in orbital dimensions and orbital velocities of the primaries, argue for unusual uniformity of physical and other conditions.

The following explanation has suggested itself to account for the variations of light of these systems. It is put forward, not as a finished theory, but in the hope that it may aid in the discovery of the complete one.

The actual variation of light is caused chiefly by changes in the light of the *secondary* due to disturbances in the part of its orbit near periastron, similar in principle to the brightening of a comet near perihelion. Where the angles of periastron of the primaries are about 90° as above, at the time of maximum velocity of *approach of the primary* (when the maximum of light occurs) both bodies

have passed periastron, the secondary receding from the observer. If we assume that there may be a lag in the production of the greatest amount of light after maximum gravitational disturbance (as seems almost certain to occur, judging from our experience with comets), the maximum of light might occur at *about* the time of maximum *approach of the primary.*

It should be observed that the coincidences are not exact (although the discordances are small), that the periods are short, and the discordances may be relatively appreciable. Similar reasoning leads to the occurrence of the minimum of light after the apastron passage at about the time of greatest velocity of recession.

It seems not improbable that the type of spectrum of the secondary at its maximum may be earlier, with few lines, thus causing the change of maximum intensity in the spectrum toward the violet observed by Albrecht and others. It may be pointed out that the velocity of the companion at periastron must be very high, in all probability sufficiently high to destroy any fine lines which might otherwise appear. Evidence bearing upon this matter is difficult to obtain with the high-dispersion spectrographs used for this work, on account of the long exposures required, perhaps also because the increase of brightness is not sufficient to bring out the characteristics of the spectrum of the secondary and because of the falling of absorption lines of one spectrum on bright regions of the other. It would seem that this matter could be best investigated with low dispersion on a bright star—where the exposures could be made very short with a view to detecting the spectrum of the secondary at maximum rather than the accurate measurement of velocities. It is also possible that a considerable increase of brightness may take place in the primary owing to the excitation of the near approach of the secondary.

Table III exhibits the intervals after periastron at which the maximum of light occurs and also the relation of minimum light to periastron. A glance at these results shows at once a relation in general between the length of period and the interval after periastron. Further examination shows also an apparent effect of eccentricity—the greater eccentricities hastening the maximum and the smaller eccentricities retarding it.

There is probably also an effect due to the relative masses of the secondaries, but on account of the uncertainties in this factor because of the unavoidable presence of the orbital inclination, it is difficult or impossible to allow for it.

TABLE III

Star	Maximum Light after Periastron		Minimum Light before Periastron
	Observed	Computed	
RR Lyrae	$0^d.06$	$0^d.06$	$0^d.05$
SZ Tauri	0.34	0.32	1.23
RT Aurigae	0.26	0.45	0.95
T Vulpeculae	0.05	0.40	0.85
δ Cephei	0.59	0.47	0.87
Y Sagittarii	1.42	2.57	0.47
X Sagittarii	0.62	0.70	2.24
η Aquilae	1.06	0.75	1.09
W Sagittarii	1.64	1.91	1.02
S Sagittae	1.83	1.74	1.25
ζ Geminorum	6.38	2.67	0.18
Y Ophiuchi	8.45*	4.04	1.26*
SU Cygni	2.07	1.68	0.10

* The periastron position of Y Ophiuchi has been assumed to be in accordance with the light-curve, which seems to show more definite eccentricity than the velocity-curve.

I have attempted a general representation of the group upon the basis of the period, eccentricity, and mass-ratios, and find the best approximate representation to be from

$$I = +0^d.27 \cdot P \cdot \left(\frac{r}{r_1}\right)^2 \cdot \sqrt{M},$$

in which

I = interval after periastron,

P = period in days,

r, r_1 = periastron and apastron distances, respectively,

$$M = \text{mass-ratio} = \frac{m_1^3 \sin^3 i}{(m+m_1)^2}.$$

The computed intervals are given in Table III.

The representation appears to be better on the whole for those stars whose periastron angles are nearest to 90°, as shown by Table IV.

With the exceptions of ζ Geminorum and Y Ophiuchi, the representation appears to be as good as the present uncertainties justify us in expecting.

TABLE IV

	ω	O−C
Y Ophiuchi	22°?	$+4^{d}41$
ζ Geminorum	333	+3.71
SU Cygni	346	+0.39
Y Sagittarii	32	−1.15
η Aquilae	69	+0.31
W Sagittarii	70	−0.27
S Sagittae	70	+0.09
SZ Tauri	77	+0.02
δ Cephei	85	+0.12
X Sagittarii	·94	−0.08
RT Aurigae	95	−0.19
RR Lyrae	97	0.00
T Vulpeculae	111	−0.35

It may be noted that ζ Geminorum and Y Ophiuchi have the longest periods and have periastron angles of 333° and 202° (or 22°), differing considerably in this respect from the majority of the stars of the group. So far as such meager data may be interpreted, it seems to point to some sort of real difference of these two stars. SU Cygni, it may be noted, shows similar peculiarities. The star RR Lyrae, resembling the cluster variables, is included with the Cepheids, as it appears to have all of the characteristics of such stars.

In suggesting the foregoing explanation of the variations in brightness of the Cepheids I am not unmindful of the great weight which must attach to the relations between maximum and minimum light and maximum velocities of approach and recession first pointed out by Albrecht. These appear to be more than mere coincidences. The same appears to be true of the present explanation. It can hardly be mere coincidence, especially as it gives considerable evidence of resting upon well-known physical bases.

The two conditions must be harmonized in some way or explained, for as yet it is not clear why there should be any connection, except possibly in the cases in which the periastron is not far from 90°.

It is not at all clear why the periastron position should depend upon the production of maximum light in such a way as to bring the latter near the descending (or any) node of the primary as it appears to do in several of the foregoing cases.

If I may hazard a guess it would be that when (or if) enough data become available concerning these stars much light will be thrown, not only on the causes of their variations in brightness, but on the gravitational effects of the Milky Way itself.

Observatorio Nacional Argentino, Córdoba
February 20, 1915

AN APPARENT DEPENDENCE OF THE RADIAL VELOCITIES AND PROPER MOTIONS UPON MAGNITUDES AND SPECTRAL SUBDIVISIONS OF THE STARS WITHIN CLASS B

By C. D. PERRINE

During an investigation of the distribution of the nebulae and variable stars some peculiarities were suspected in the distribution and velocities of the stars of class B with reference to magnitude. The following tables exhibit the results of an examination of the stars contained in Campbell's catalogue in *L. O. Bulletin* No. 195.

The ranges of magnitude adopted are entirely arbitrary for the sake of convenience.

TABLE I

Limits of Magnitude	Galactic			Non-galactic			All			
	No. of Stars	Residual	Mean V_1	No. of Stars	Residual	Mean V_1	No. of Stars	Residual	Mean V_1	Percentage
		km	km		km	km		km	km	
2.2 and brighter..	15	+0.6	3.2	3	−0.5	2.7	17	+0.4	3.2	0
2.3–2.9.........	14	+3.5	5.9	2	−5.1	9.9	13	+2.3	6.7	23
3.0–3.9.........	38	+1.1	5.6	5	−1.9	2.1	43	+0.8	5.2	14
4.0–4.9.........	80	−1.0	6.2	33	−2.4	6.7	112	−1.6	6.6	19
5.0.............	21	−2.5	9.3	15	−2.0	6.4	36	−2.4	8.2	31
Variables........	.....	.....	.....	.....	.....	.....	4	−1.6	5.5	0
*4.0–4.9........	.....	.....	.....	12	−2.1	9.0	.....	.....	.....	.....

* Galactic latitudes ±40° to ±90°.

Note.—The last column contains the percentages of stars in each group which have velocities of 10 km and over.

The galactic limits were taken as 20° either side of the mean galactic plane, embracing an area a little more than one-third of the entire sky.

An examination of the individual results shows that if we separate the first group into two—stars of 1.5 and brighter, and stars fainter than 1.5—we have the following:

	No. of Stars	Residual V	Mean V
		km	km
1.5 and brighter.............	4	+0.3	0.5
1.6–2.2.....................	13	+0.3	4.1

The group 2.3–2.9 appears to be abnormal, owing to the effect of three large values of *V*, in the small number of 13. If we reject these three, the value of residual *V* becomes +1.0 and of mean *V*, 3.8, which agree well with the others.

As the B8 and B9 stars appear, in some respects at least, to be somewhat different from the other stars of class B, the effect of omitting these stars on the foregoing investigation was tried. The result is given in Table II for all stars.

TABLE II

	No. of Stars	Residual *V*	Mean *V*
		km	km
2.2 and brighter	15	+0.3	3.4
2.3–2.9	12	+1.3	6.1
3.0–3.9	38	+0.3	5.5
4.0–4.9	88	−0.7	6.2
5.0	24	−2.7	8.9

In Table III are given similar data for the B8 and B9 stars.

TABLE III

	No. of Stars	Residual *V*	Mean *V*
		km	km
2.2 and brighter	2	− 1.6	1.6
2.3–2.9	1	−14.5	14.5
3.0–3.9	5	− 4.2	4.7
4.0–4.9	24	− 4.6	7.7
5.0	12	− 2.0	7.0
All	45	− 3.9	7.0
Galactic	23	− 2.5	4.3
Non-galactic	22	− 5.3	9.8

An examination of the individual velocities shows considerable uniformity within the groups; the wide differences between the extreme groups is evident at a glance.

An investigation of the proper motions of these stars also reveals an apparent dependence upon magnitude as in the following tables.

TABLE IV

CLASS B–B5 ALL PARTS OF SKY

Magnitude	No. of Stars	Mean μ
2.2 and brighter.....	16	0".047
2.3–2.9.............	12	.032
3.0–3.9.............	38	.028
4.0–4.9.............	88	.024
5.0.................	24	0.025

TABLE V

B8 AND B9 STARS ALL PARTS OF SKY

Magnitude	No. of Stars	Mean μ
2.9 and brighter.....	4	0".088
3.0–3.9.............	5	.049
4.0–4.9.............	24	.046
5.0.................	12	0.040

TABLE VI

B–B5

	GALACTIC		NON-GALACTIC	
	No. of Stars	Mean μ	No. of Stars	Mean μ
2.2 and brighter..........	12	0".027	3	0".087
2.3–2.9..................	12	.033	0	....
3.0–3.9..................	35	.029	3	.021
4.0–4.9..................	66	.024	5	.013
5.0......................	18	0.024	4	0.030
All......................	143	0.026	15	0.034

The non-galactic results in these investigations have but little weight owing to the few stars of this class which are situated far from the galaxy. It was suspected that the proper motions of the non-galactic stars might be greater than those of the galactic stars, brightness for brightness, and that the fainter stars, being more widely distributed, might have caused the apparent dependence upon magnitude when in reality it was a dependence solely upon

galactic latitude. This point will be investigated further in other classes of stars where the conditions are more favorable.

TABLE VII

B8–B9 STARS

	Galactic		Non-galactic	
	No. of Stars	Mean μ	No. of Stars	Mean μ
2.9 and brighter	3	0″.063	1	0″.162
3.0–3.9	4	.047	1	.058
4.0–4.9	14	.032	10	.070
5.0	4	.040	8	.040
All	25	0.039	20	0.062

Attention should be called especially to the apparent contradiction between the radial velocities and proper motions so far as dependence upon magnitude is concerned—the velocities appear to *increase* with decreasing brightness whereas the proper motions *decrease*.

In view of the peculiar systematic error which appears to exist in the radial velocities of practically all stars, and its particularly large value for the class B stars, no attempt is made at present to analyze this matter further.

The proper motions have not been cleared of the effects of the motion of the solar system, which is somewhat uncertain owing to the necessity of making assumptions as to distances. Any such effects with respect to magnitudes are probably practically negligible. There may be a noticeable effect between the galactic and non-galactic results, but it is believed hardly enough to wipe out the entire differences shown above.

The spectral subdivisions in stars of class B appear to show a similar increase in proper motion as found by Professor Boss for class A stars.

It was suspected that the real cause of this variation might be spectral subdivision rather than simply magnitude. There is an undoubted tendency for the brighter stars to belong to the earlier subdivisions, but the dependency seems to be chiefly upon magnitude, as shown by Table VIII.

TABLE VIII

Class	2.9 and Brighter		3.0 and Fainter	
	No. of Stars	Mean V_1	No. of Stars	Mean V_1
		km		km
B –B2	19	3.7	34	7.1
B3–B5	8	6.7	113	6.3
B3–B5*	6	3.2	....	....
B8–B9	3	5.9	41	7.1
All	30	4.7	188	6.6

* Rejecting two large values of V.

The effect was tried on the B–B5 stars using the values V_2 instead of V with the following results:

TABLE IX

	No. of Stars	Residual V_2	Mean V_2
		km	km
2.2 and brighter	15	+1.5	3.8
2.3–2.9	12	+5.0	6.2
3.0–3.9	38	+2.2	5.5
4.0–4.9	88	0.0	6.5
5.0	24	−1.3	8.4

From these data the following conclusions are tentatively drawn:

A. That the average radial velocities of the B stars discussed depend in general upon magnitude, the *velocity increasing* with *decrease of brightness.*

This seems to be true for galactic and non-galactic regions and to some extent true also for the stars of classes B8 and B9. In these latter stars there appears to be a great difference between the velocities in the galactic and non-galactic regions.

B. There appears to be a relation in general between the brightness of these stars and their type—the brighter stars "preferring" the early classes—B, B1, and B2, the fainter stars B3, B5, B8–B9.

C. The *residual* radial velocities (V_1) of the brighter B stars within 20° of the plane of the Milky Way show a progressive tendency with magnitude—i.e., a small *positive* radial velocity for

the group 2.2 magnitude and brighter which changes to a *negative* radial velocity for the stars fainter than 4.0 magnitude.

D. The residual velocities of the non-galactic B stars appear to be consistently *negative* for all magnitudes. Of the 58 non-galactic stars discussed, 22 have positive values and 36 negative values.

E. The proper motions of the B stars appear to be functions of the magnitudes.

The B–B5 stars have been charted in groups by magnitude, also the B8–B9 stars and those with velocities of 10 km and over.

The following conditions regarding their distribution are indicated:

M. All of the charts show that the plane of distribution of the B stars does not coincide exactly with the plane of the Milky Way but falls *below* or *southwest* of it in the regions $\alpha 3^h$–$7^h \pm$ and *above* or *north* in the region 12^h–16^h.

It may be noted that the first region is that of the Orion Nebula and the second that of the Eta Argus-Crux region of the Milky Way. These tendencies appear to strengthen the connection of these stars not only with the galaxy but with the most important nebulous regions.

N. The apparent distribution of these B stars is a function in general of the magnitude—the fainter stars being found over a wider area than the brighter ones.

An examination of the magnitudes of the B8 and B9 stars shows that in general they are faint, only eight being brighter than fourth magnitude and three brighter than the third magnitude, out of 45 examined. In the matter of distribution these B8 and B9 stars appear to be more widely scattered than the B–B5 stars of equal magnitudes, as pointed out by Campbell.[1]

Two additional tendencies are to be noticed:

A number of the fainter stars, including B8 and B9 and stars of large velocity, are found in the region not far from the two Nubeculae.

The region of the Milky Way and sky from 18^h to 0^h is entirely free from the brighter stars and almost entirely so from the stars

[1] *Lick Observatory Bulletin No. 195*, p. 107.

fainter than 5.0, *but contains the normal proportion of stars 4.0–4.9.*

There appears to be some tendency to grouping of stars with similar velocities. These have not been studied in detail.

A consideration of related facts, including proper motion, and having in mind the large difference in mean radial velocities between the B and A stars, indicates that the large range found above in the mean velocities within the B stars is real.

Should these conditions prove to be representative of the group, as appears entirely probable, it would seem that here we have further evidence of being near the origin of these stars—and strong evidence that the velocities of translation of the matter forming these stars was low during their early stages of development.

CONCLUSIONS

The following conclusions may be summarized from this investigation:

1. Within class B the inherent velocity of the stars is in general a function of the brightness and of the spectral subdivisions, these two conditions being related.

2. The radial velocities at the beginning of the series, i.e., the brighter stars and those of the early spectral subdivisions, are very nearly zero.

3. In general the fainter stars and those of later subdivisions have inherent velocities of between 8 and 9 km per second—connecting well with the values of 8.6 km for Ap and 10.3 km for A found in an investigation of the class A stars.

4. The apparent distribution of the B stars in the sky with respect to the Milky Way is also a function of magnitude, spectral subdivision, and inherent radial velocity, the fainter, later spectral subdivisions and larger inherent velocities being found farther from the galactic plane.

5. A variation of residual radial velocity for each group according to magnitude, etc., is indicated, but in view of the probable rapid variation of internal conditions it seems not advisable to draw any conclusions until more data are at hand. If this progressive effect is sustained such a condition is very suggestive.

The foregoing results may be considered to strengthen further the discovery by Campbell, Kapteyn, Frost and Adams of the variation of inherent velocity of the stars with supposed increasing age. It further tends to place the early velocity close to zero and to show that the velocities increase regularly and not by jumps.

Observatorio Nacional Argentino
Córdoba
February 8, 1915

Minor Contributions and Notes

SOME RECENT DISCOVERIES IN SPECTRUM SERIES

During the past few years our knowledge of the subject of spectrum series has been very greatly enlarged. The classical work of Kayser and Runge left many physicists with the impression that little more was to be done, but the "combination principle" of Ritz served as a starting-point for a great advance. The larger part of this advance we owe to Paschen and to Fowler. During the past year a Doctor's dissertation (Tübingen) by E. Lorenser, working under Paschen, has furnished some new results, and a remarkable contribution to the subject has just been made by Fowler in his Bakerian Lecture (*Phil. Trans.*, **214**, 225, 1914). The present brief review of these two pieces of work is presented in the hope of making plain to those interested in atomic vibrations the nature of the problem which awaits the man who seeks to devise a working model of an atom.

The work of Lorenser includes some excellent measurements, chiefly in the red, on the spectra of Mg, Ca, Sr, and Ba, and a presentation of some of the series of these elements, of which a few are new, and some perhaps a little doubtful. Fowler's paper deals largely with series in the "enhanced" spectrum of Mg, including a survey of some of the series of other elements also. As the mass of material in these two papers is too great for condensation into a brief review, it seems sufficient to consider Mg alone, since we know rather more about its spectrum than about those of kindred elements, and because it is an interesting and probably typical system.

A brief introductory statement about notation will help. Every series consists of a converging arrangement of lines, or "members," each of which may be complex and contain from one to six lines. The difference in "wave-number" (number of waves

per cm) between the limit of the series and each member is called the "term." A series may be approximately represented by a formula, the exact nature of which is not known, and is not always important; one type (Mogendorff and Hicks) is

$$\nu=\frac{1}{\lambda}=\text{limit}-\frac{N}{\left(m+a+\frac{b}{m}\right)^2}$$

in which N is the "universal series constant," a and b are constants of the individual series, and m is a variable integer. This formula may be symbolically written $\nu=\text{limit}-(m, a)$ which has degenerated in practice to $\nu=\text{limit}-ma$. The limit itself is commonly a "term" of some other series, and the different series are distinguished by appropriate letters for the constants, p, s, d, and f, so that the abbreviated designation of the formula becomes $1s-mp$, or $2d-mf$, or whatever the case may be.

The theory recently published by Bohr indicates that in certain cases the constant N may have to be replaced by $4N$, and it is possible that N may apply to those series whose vibrations are due to the neutralization of an atom lacking one electron, while $4N$ is required when the atom, having lost two electrons, regains one and vibrates as it does so.

The spectrum of Mg consists of three main systems, composed of triplet, pair, and single-line series. Of these, the pair system has been greatly extended by Fowler's latest work, and he has shown that the constant $4N$ is required for all the series of this system, while N alone is proper for all other series in Mg. The same remark applies to corresponding series in kindred elements, and also to what was supposed to be the principal series of hydrogen, which Bohr and also Fowler now regard as due to helium. This whole group of series is variously designated as "spark" or "enhanced" series, because of their behavior, though these designations are not ideal, as the lines may be obtained from many different sources of light.

Within each of these three systems there are, in general, four different *types* of series, known as "principal," "sharp" (second subordinate), "diffuse" (first subordinate), and "fundamental"

(Bergmann). These names are not always very appropriate; for instance, the "sharp" series is often diffuse, and the "fundamental" series may be composed of the faintest lines in the spectrum; but this is not vital. Each type gives a series of "terms" which are, of course, quite different from one another. They may be listed as mp, ms, md, and mf for the triplet system; $m\pi$, $m\sigma$,

TABLE I

SERIES IN THE SPECTRUM OF MAGNESIUM

Formula	Series Letter	Remarks	Fowler's Designation
Pair system—			
$1\sigma - m\pi$	π	Principal series, wide pairs	P
$1\pi - m\sigma$	σ	Sharp series, wide pairs	S
$1\pi - m\delta$	δ	Diffuse series, wide pairs	D
$2\delta - m\phi$	ϕ	Fundamental series, narrow pairs	4481 series
$3\delta - m\phi$	ϕ'	Very narrow, observed as single	A
$3\phi - m\phi$	ϕ''	A single-line series in the pair system	B
$2\sigma - m\pi$	π'	Minor series of principal type	$FP(p)$
$2\delta - m\pi$	π''	Same. One member observed	C
$2\pi - m\sigma$	σ'	Minor series, sharp type	$FP(s)$
$2\pi - m\delta$	δ'	Minor series, diffuse type	$FP(d)$
Triplet system			
$1s - mp$	p	Principal series, wide triplets	
$1p - ms$	s	Sharp series, wide triplets	
$1p - md$	d	Diffuse series, wide triplets	
$2d - mf$	f	Fundamental; narrow; observed as single lines	
$1p - mf$	f'	(Possible) series of narrow triplets	
$1p - mp$	p'	(Possible) series of principal type	
Single-line system—			
$1S - mP$	P	Principal series, runs into Schumann region	
$1P - mS$	S	Sharp series (Fowler)	
$1P - mD$	D	Diffuse series, Rydberg's	
$2S - mP$	P'	Minor series of principal type	
$1P - mP$	P''	Another of principal type	
Inter-system series—			
$1S - mp$	Sp	Single-line series with principal-type terms	
$2D - mf$	Df	(Possible) series of fundamental type	

$m\delta$, and $m\phi$ for the pair system; and mP, mS, mD, mF for the single-line system. These series of terms recur in different parts of the spectrum, converging to different limits, thus producing "shifted" or "parallel" series, two of which are exactly alike in all wave-numbers, if a constant is added to the wave-numbers of one of them. Series of the principal type consist (unless they are

single lines) of groups of lines which converge to a single line as a limit: series of the sharp and fundamental types are made up of groups whose wave-number differences are constant; while series of the diffuse type combine both sets of features, the group constituting the series-member being complex at first, but converging toward a simple group of the same character as the corresponding sharp series.

The Rydberg-Schuster law was the forerunner of others of the same sort. All of them can be grouped into the statement that the limit of a series is itself a term of some other series. In some cases, however, the first "term" of a series must be formed by treating the wave-number as negative, and in these cases the corresponding series-member occurs in the spectrum wrong way around, that is, with the line which is expected to have the shorter wave-length appearing on the long-wave side, and the intensities also reversed.

With this preamble, then, the table of series of Mg here given may take on some significance. In our abbreviated notation some differences exist in practice as to the numeration adopted for m; the values here used correspond to Fowler's latest work and differ from those of Ritz, Paschen, or Lorenser. It must be noted that each term $m\pi$ has two values (since these series-members are double) which may be designated separately, if desired, as $m\pi_1$ and $m\pi_2$; δ is also double, and p and d are triple. The second column of the table contains a suggested system of series lettering which may be convenient for reference. In the single-line system it will be noticed that no series of the fundamental type has yet been found. Such series exist, however, in certain other elements. At the bottom of the table there is a section devoted to "inter-system" series. These are derived in a way sufficiently indicated by their formulae, and they are extremely interesting, as they are combinations between the triplet and single-line systems. It is significant that no combinations are known between the pair system and either of the others; this fact, together with the use of $4N$ in the formula, indicates that the pairs originate in a different vibrating atom from the other lines; but the single lines and the triplets are apparently given by the same kind of atom. The inter-system series are relatively more conspicuous in other spectra (e.g., Hg).

There is little doubt that still more series are to be discovered in the Mg spectrum, but, as it stands, the entire system involves twenty positively established series and some other likely ones. This is a sufficiently formidable complex to alarm the bravest constructive mathematical physicist, but we may be thankful that it is no worse. The series are quite closely interrelated, most of the known lines in the spectrum are now properly labeled, and we have a handy filing system adapted to the reception of new series as they are discovered.

A word should be added in regard to the sources of light required to bring out these various series. All the systems are represented in the spectrum of the ordinary arc in air (as well as the vacuum "vapor lamp"). The triplet and single-line systems are well developed in the arc, the latter best near the positive terminal. The single-line system is strongly given by the electric oven, as is also the series called *Sp* in the table. The vacuum arc emphasizes the pair system, especially in the region close to the negative terminal, from which Fowler obtained many of his new series; the stronger lines of this system occur also in the spark in air, but are too diffuse for accurate observation. For the outer members of most series the best conditions seem to be a discharge through a considerable depth of luminous vapor at a low pressure.

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Reviews

Polhöhen-Schwankungen. (Sammlung Vieweg, Heft 11.) By E. Przybyllok. Braunschweig: Friedr. Vieweg & Sohn, 1914. 8vo, pp. 41, figs. 8. M. 1.60.

The "Sammlung Vieweg" has set itself the task, so its advertisement reads, of making more widely known through clearly written, compact discussions those realms of research and those scientific theories that are at the present time in a state of development; and, in particular, it undertakes to show the present status of the various problems. Through this procedure it hopes to facilitate the ready comprehension of modern scientific developments and to point out the direction in which further research is to proceed.

This ambitious series of small treatises, which already includes memoirs on flying machines, gravitation, and sugar beets, is capably represented astronomically in the booklet that is the subject of the present review. Dr. Przybyllok does for the problem of latitude variation exactly what the editors have advertised. He presents his subject briefly, clearly, thoroughly, and without introducing details of the serious mathematical discussions that are at the basis of so many phases of the practical investigation. The history of the sixty years of suspicion that culminated finally in the general admission of the inconstancy of terrestrial latitude, the development of the problem during the last thirty years into an international project, the theories and suggestions that have been advanced to account for the observed and suspected motions of the pole and for the ever-present systematic deviations at different stations, and finally the present state of our knowledge of latitude variation—all are treated here in sufficient detail for the purpose, and the most significant literature of the subject is cited throughout in the footnotes. Charts showing the path described by the pole from 1890 to 1913 are given on a folded insert at the back of the book.

As might be expected, much of the latter half of the treatise deals with the detection and measurement of the elusive Kimura term and with the interpretative speculations concerning it. Some of the latest considerations on this point, however, are not mentioned. None of the two or three small errors noticed throughout the work are worth mentioning,

unless one would care to remark that the Hawaiian Islands are in the Northern Hemisphere.

It is interesting in this time of serious international political disturbances to observe that the development of the study of latitude variations has depended entirely on peaceful international alliances. Nearly all of the great governments have taken part in the latitude service, co-operative observations have been made toward the solution of this one problem in all parts of the world, and men of a dozen different nationalities have worked together toward the same goal. What effect the present world-conflicts may have on the continuity of the international latitude investigations is uncertain. The possibility that the work in the United States may suffer is suggested in the resolutions recently adopted by the American Astronomical Society and by the Astronomical Society of the Pacific asking the government to make some special provision for the maintenance of the stations in this country.

HARLOW SHAPLEY

Données numériques de spectroscopie. Extrait du Volume III des *Tables annuelles de constantes et données numérique.* Paris: Gauthier-Villars et Cie, 1914. (Chicago: The University of Chicago Press.)

Portions of Volume III of the "International Tables of Constants and Numerical Data, Chemical, Physical, and Technological" have been issued in separate folios as follows:

Title of Folios	Editor	No. of Pages	Price in Francs
A. Spectroscopie	L. Brüninghaus	74	10
B. Électricité, Magnétisme Conductibilité des électrolytes Forces électromotrices	Dr. L. Mahlke Professor W. C. McG. Lewis Professor F. Dutoit	79	10
C. Électronique, Ionisation, Radioactivité	J. Saphores	9	2.50
D. Cristallographie et Minéralogie	L. J. Spencer	19	4
E. Biologie	L. Terroine	17	4
F. Art de l'Ingénieur Métallurgie	G. Fiek, W. Hinrichsen S. L. Archbutt, Portevin, Nusbaumer	74	10

The folio on spectroscopy, which should be of especial interest to readers of the *Astrophysical Journal*, comprises pp. 165–238 of the complete volume. It contains an introduction by M. H. Deslandres, a list

of chapters, and a list of the substances for which spectroscopic data are given. It is grouped under the following chapters: (i) "Description of Emission Spectra"; (ii) "Zeeman Effect"; (iii) "Displacement or Broadening of Spectral Lines under Pressure"; (iv) "Relations between the Intensity of Spectral Lines and the Conditions of Excitation"; (v) "Velocity of Propagation of Luminous Vapors in the Spark"; (vi) "Series Grouping of Lines or Emission Bands or Absorption Bands"; (vii) "Absorption Spectra of Gases and Vapors of Elements and Inorganic Substances"; (viii) "Absorption Spectra of Gases and Vapors of Organic Substances"; (ix) Absorption Spectra of Inorganic Substances in the Solid or Liquid Form or in Solution;" (x) "Absorption Spectra of Organic Substances in the Solid or Liquid Form or in Solution"; (xi) "Absorption Spectra of Various Substances of Animal or Vegetable Origin."

Under each chapter head the titles are arranged in alphabetical order of the chemical symbols or in alphabetical order of the names of the bodies. There are, in all, 146 tables of data. It is a considerable advantage to have these separate folios available, as the complete volume is not only too expensive for very wide circulation but is rather cumbersome.

H. G. G.

The Earth, Its Life and Death. By A. Berget. Translated by E. W. Barlow. New York: Putnam, 1915. Pp. 366. $1.50.

With the entertaining vivacity of style for which the French are celebrated, the author presents to the well-educated layman some of the more interesting facts known about the earth as a planet. The central chapters deal with the form and mass of the earth, its motions as a planet, volcanic and seismic phenomena, gravity, electricity, and magnetism of the earth, the circulation of the winds and oceans, and other physical considerations. In the opening chapter the origin of the earth is sketched, largely according to the time-honored theory of Laplace. The nebula is imagined to have been one of the spiral type and is explained by the actual collision of two dark suns. An appropriate old age and death of the earth and solar system are supposed to be conditioned by the progressive radiation of heat which it is thought will render the earth uninhabitable within a few million years.

Here and there the volume contains evidence that the author is not fully abreast of modern progress in geology and astronomy, although his familiarity with physics seems to be of a much higher order. Some

of the lapses have been tactfully corrected by the translator but these are mostly cases of detail. In the reviewer's estimation, the greatest disadvantage of the book is closely related to its charming style. Many ideas which are really highly speculative are so ingeniously woven in with well-determined facts or established theories that the argument appears most plausible. It is doubtful whether the lay reader will be sufficiently on his guard, or will have the necessary technical knowledge, to enable him to discriminate between what is reliable in the book and what is strongly colored by the author's somewhat naïve deductions.

E. B.

Astronomy. By G. F. CHAMBERS. New York: D. Van Nostrand Co., 1913. Pp. xxiv+335, figs. in text 68, plates 135. $1.50.

In this profusely illustrated volume, with text that is in general simple and straightforward, there is much that is very attractive. But, on the other hand, there is revealed a narrowness and an inappreciation of modern advances, that makes the work savor of the pre-spectroscopic age. True, in the introduction, the author states, "It will be my endeavor to keep as closely as I can to astronomy in the older and more limited sense." No fault need be found with this limitation providing the author does not at the same time close his mind to the testimony from astrophysical sources bearing on the topics considered. Fields are left barren, phenomena are left unexplained, or suggested explanations, for which the older astronomy furnishes no test, are left vague, though results, sound explanation, and proof are available from other sources. A few samples will serve to illustrate:

On p. 214, concerning the Algol variables, "By way of explanation it has been suggested that a non-luminous satellite revolves round the primary star and eclipses it at stated intervals." A mere suggestion, nothing more. On p. 232 the author professes himself as unconvinced of the gaseous nature of the so-called gaseous nebulae. The observers of the astrophysical observatory of the Smithsonian Institution will be grieved to read on p. 23, "Though attempts have been made to calculate and state by figures the heat-giving power of the sun, it must be obvious that all such calculations can only be, if not quite imaginary, yet very wild and indeterminate." On p. 309, "Though the whole idea of such an attempt to prove stellar movement by means of the spectroscope seems a high flight of the imagination, yet it does not appear that there are sufficient grounds for distrusting the results arrived at in the case of several dozen stars, though these results require us to talk about

miles per second as the pace at which the stars in question are travelling to and from somewhere." On p. 122, and again on p. 306, it is stated that helium is not found on the earth.

But even in the field to which this book is ostensibly devoted it is not free from fault. There is no mention of the stellar parallax problem, and proper motion is dismissed in a phrase. On p. 242 he states, "The Milky Way . . . . is one vast nebula running around the heavens in the form of a belt." When we think of the great nebulous fields in Ophiuchus and Sagittarius, this seems not so fantastic did we not find on p. 241, "Subject to certain special exceptions, the fixed stars are distributed fairly evenly over the whole sky." These special exceptions do not seem to refer to the gradual thinning out of stars with increasing galactic latitude. On p. 83 we find the term "germination," in quotation marks, applied to the doubling of Martian canals. On p. 112 the asteroid (699) is noted as the one having the most and least eccentric orbit. On p. 110 it is stated that the only asteroids worthy of consideration are the four first discovered and Eros. Even the Achilles group is apparently of no interest. A considerable discussion of the solar rotation makes no mention of the most interesting thing about it, the equatorial acceleration. On p. 8, "Spots often start from a pore as a place of origin." This is most decidedly not the case. It is interesting to contrast the degree of positiveness of the following two statements: concerning sun-spots, p. 15, "The periodicity of 11.1 years is now established to a *dead certainty*"; and concerning Neptune, p. 106, "The existence of one satellite *seems* to be assured." On p. 228, in speaking of the nebulous matter in the Pleiades, the astonishing statement is made that it has had its origin in the last half-century. Similar evidence might convince one that stars below the naked-eye limit were created about 1610. Just one other matter, and that is concerning the vivid and very misleading representation of the colors of double stars in plates 84 and 85. It is said that if one inverts himself by standing on his head, color contrasts are greatly enhanced. I doubt if less drastic revolution of method of observing would reveal the colors as represented.

There is perhaps little of commendation in what precedes; there is certainly no notion to recommend the book as a reference authority. Nevertheless in it there is much that is admirable and many readers will doubtless get a taste for astronomy from it. But, on the whole, the author cannot be said to have enhanced the esteem with which he was regarded as the author of Chambers' *Handbook of Astronomy*.

P. F.

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ANOMALOUS DISPERSION IN THE SUN

By SEBASTIAN ALBRECHT

INTRODUCTION

In recent years, Professor Julius has published a number of articles in which he developed the theory of anomalous dispersion, with special reference and application to solar phenomena. As the writer required, in another line of work, a detailed knowledge of the accidental as well as the systematic errors in Rowland's Table of Solar Spectrum Wave-Lengths, it became necessary, among other things, to test these wave-lengths for possible effects of anomalous dispersion. Before proceeding with the account of that test, the writer will state briefly such of the principal deductions from the anomalous-dispersion theory as will enable the reader to gain at least a partial insight into the causes which, it is supposed, underlie the effects discussed in this article.

By anomalous dispersion is denoted the general property of matter that its refracting power $\pm(n-1)$ varies rapidly as we approach an absorption line. Two of the effects of the property of anomalous dispersion are (*a*) anomalous refraction and (*b*) anomalous scattering. Anomalous dispersion subsists even when the density of the medium is perfectly uniform and the propagation of

light rectilinear. In that case anomalous scattering only is operative. Rayleigh's formula for the coefficient of scattering (s) is

$$s=\frac{32\pi^3(n-1)^2}{3N\lambda^4},$$

where N is the number of scattering particles per unit volume, and λ is the wave-length of the light under consideration. We see that s passes through a sharp maximum in the neighborhood of every λ which corresponds to an absorption line, because there the factor $(n-1)^2$ increases rapidly as we approach the line from either side. Even absolutely monochromatic absorption would thus, in an extensive atmosphere (even with a medium of perfectly uniform density and with rectilinear propagation of light), give rise to a line of a certain width. Every absorption line of a stellar atmosphere is, therefore, enveloped in what is called a dispersion band. It is through asymmetry of the dispersion band that displacements of lines by anomalous dispersion take place, for the true absorption line cannot be displaced by this cause.

More recently Julius[1] has developed an extension of the anomalous-dispersion theory, according to which there must be a mutual influence of Fraunhofer lines. As the position "of a certain line A depends on the refracting power of the medium for the adjacent waves, it must be influenced by the presence of a strong neighboring line B." In other words, Fraunhofer lines which are close to each other exert a mutual influence upon each other. This is one of the ways in which asymmetries are produced in dispersion bands. The theory requires that the influence be opposite in direction in the two cases where the line B lies toward the red or toward the violet of line A, and in addition, that when B lies on the red side of A the influence must be greater than when B lies on the violet side. It is this effect which lends itself most readily to the test proposed, and for convenience the writer will refer to it as the Julius effect. Other effects of anomalous dispersion will not be considered here, and for further details in regard to the theory the reader is referred to the original articles by Julius.

[1] *Astrophysical Journal*, **40**, 1, 1914. (References to earlier articles by Julius will be found here.)

Julius (*op. cit.*) has himself made a test for this effect, using as a basis St. John's measurements of displacements of the Fraunhofer lines at the edges toward center and limb of eccentrically located sun-spots. Julius refers to these displacements in sun-spot spectra as the Evershed effect. His problem was to select from St. John's list such lines as have close companions, either to the red or to the violet, of sufficient strength to produce the anomalous dispersion outlined above. If anomalous dispersion is operative, then the lines thus selected should show respectively a decrease or an increase in the amount of the Evershed effect. Julius obtained results which indicated that this does actually occur.

A more recent rediscussion of the same data led St. John[1] to conclude that no such decrease or increase in the amount of the Evershed effect is shown, though he considered the material to be suitable for a definitive test of the Julius effect.

The present investigation is based upon entirely different and independent data, namely, the wave-lengths of the iron lines in the solar spectrum as given in Rowland's Preliminary Table of Solar Spectrum Wave-Lengths. The problem in this case is to compare Rowland's wave-lengths with wave-lengths obtained in the laboratory, in order to determine whether the wave-lengths of lines having close companions respectively toward the red or toward the violet in the solar spectrum differ systematically from each other and from the lines which are not thus accompanied by close companions.

DESCRIPTION AND TREATMENT OF THE DATA

Table I contains all the lines which were examined for a possible Julius effect. As far as the writer is aware this is the complete list of lines for which the *group* according to pressure displacement is known. The choice of material was restricted to these lines,[2]

[1] *Astrophysical Journal*, 41, 28, 1915; *Mt. Wilson Contr.*, No. 93.

[2] In the summer of 1914 the writer had investigated this problem without eliminating the pressure effect. In that investigation a much larger list of lines was available, and the results are in fair agreement with those discussed in this article. However, as the pressure displacements according to the Mount Wilson groups are definitely confirmed in these reductions, and as the lines of the several pressure groups are not distributed uniformly along the spectrum nor represented in equal numbers, it is preferable to use only those lines for which the pressure effect can be eliminated.

TABLE I

FOR THE DETERMINATION OF THE RELATION BETWEEN THE ROWLAND AND THE INTERNATIONAL SYSTEMS—FOR FE

λ_{Rowland}	$\lambda_{\text{I.A.}}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{\text{I.A.}}$ at 1 Atm	$\Delta\lambda'$ for $\lambda_{\text{I.A.}}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion: Line); Separation; Etc.
3609.008	.860	*b* I	+.148	+.148½	3:20, 0.38A to vi.; 5:20, 0.46 to red
18.919	.769	*b* I	.150	.151	3:20, 0.39 and 3:20, 0.48 to vi.; 8:20, 0.62 to red
31.605	.464	*b* I	.141	.142	Relatively faint lines on each side
47.988	.845	*b* I	.143	.144	4:12, 0.43 to vi.
80.069	.915	*a* I	.154	.154½	2:9, 0.25 to vi.; 2:9, 0.46 to red
87.610	.458	*b* I	.152	.153	3:6, 0.38 to vi.; 4:6, 0.19 to red
3705.708	.567	*a* I	.141	.141½	2:9, 0.14 to red
09.389	.250	*b* I	.139	.140	Companions 1:8 on each side
20.084	.938	*a* I	.146	.147	Intensity 40. No companion
22.729	.565	*a* I	.164	.164½	3:6, 0.09 to vi.
27.778	.622	*b* I	.156	.157	Faint lines on each side. Indeterminate
33.469	.319	*a* I	.150	.150½	Faint lines on each side. Probably neutral
35.014	.869	*b* I	.145	.146	4:40, 0.47 to red
37.281	.135	*a* I	.146	.147	5:30, 0.22, and 3:30, 0.32 to vi.
43.508	.364	*b* I	.144	.145	2:6, 0.12 to red
45.717	.563	*a* I	.154	.154½	2:8, 0.23 to vi.; 6:8, 0.34 to red. Indeterminate
46.058	.900	*a* I	.158	.158½	8:6, 0.34 to vi.
48.408	.264	*a* I	.144	.144½	Only 1:10 on each side
48.650	.492	*b* I	.158	.158½	10:1, 0.24 to vi.
58.375	.234	*b* I	.141	.142½	4:15, 0.55 to vi. Probably neutral
63.945	.792	*b* I	.153	.154	Only 1:10 on each side
65.689	.541	*b* I	.148	.149	1:6, 0.16 to red. Relatively weak
67.341	.194	*b* I	.147	.148	Only 1:8 on each side
88.046	.880	*b* I	.166	.167	No companion
95.147	.004	*b* I	.143	.144	Only 1:8 on each side
3815.987	.844	*b* I	.143	.144½	3:15, 0.5 to red
26.027	.886	*b* I	.141	.142½	No relatively strong companions
27.980	.826	*b* I	.154	.155	Faint companion on each side
34.364	.227	*b* I	.137	.138	4:10, 0.14 to red; 3:10, 0.36 to vi.
86.434	.287	*a* I	.147	.147½	3:15, 0.51 to red
87.196	.053	*b* I	.143	.144½	3:7, 0.25 to vi.
88.671	.520	*b* I	.151	.152	2:5, 0.11 to vi.; 2:5, 0.30 to red
95.803	.659	*a* I	.144	.144½	3:7, 0.22 to vi.
99.850	.711	*a* I	.139	.139½	No close companion
3903.090	.950	*b* I	.140	.141½	2:10, 0.32 to vi.; 2:10, 0.31 to red
06.628	.482	*a* I	.146	.146½	2:10, 0.19 to vi.; 4:10, 0.26 to red
20.410	.261	*a* I	.149	.149½	Only 1:10 on each side
23.054	.917	*a* I	.137	.137½	Only 1:12 on each side
28.075	.925	*a* I	.150	.151	1:08, 0.14 to vi.; 2:8, 0.16 to red; 2:8, 0.28 to red. Somewhat indeterminate
30.450	.304	*a* I	.146	.147	2:8, 0.43 to vi. Relatively faint for separation

TABLE I—*Continued*

$\lambda_{Rowland}$	$\lambda_{I.A.}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{I.A.}$ at 1 Atm	$\Delta\lambda'$ for $\lambda_{I.A.}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion: Line); Separation; Etc.
3956.819	.682	*b* 4	.137	.138	Strong lines on each side. Indeterminate
69.413	.263	*b* 1	.150	.151½	6:10, 0.53 to vi.; 2:10, 0.49 to red. 700:10, 0.79 to vi.
77.891	.746	*b* 4	.145	.146	No close companion
97.547	.398	*b* 4	.149	.150	1:4, 0.29 and 2:4, 0.43 to vi.; 2:4, 0.09 to red
4005.408	.250	*b* 1	.158	.159	Faint lines on each side; and 3:7, 0.45 to red
45.975	.822	*b* 1	.153	.154½	Intensity 30. Only relatively faint lines near
63.759	.604	*b* 1	.155	.156	4:20, 0.32 to vi. Relatively faint
71.908	.748	*b* 1	.160	.161	Only very faint lines near
4132.235	.063	*b* 1	.172	.173½	2:10, 0.14 to vi.; 3:10, 0.46 to red
34.840	.685	*b* 4	.155	.156½	3:5, 0.25 to vi.; 3:5, 0.35 to vi.
44.038	.873	*b* 1	.165	.167	4:15, 0.47 and 2:15, 0.37 to vi.
47.836	.676	*a* or *b*	.160	.161	2:4, 0.33 and 1:4, 0.19 to vi.
91.595	.443	*a* or *b*	.152	.153	3:6, 0.25 to red
91.843	.678½	*e*	.164½	.161	6:3, 0.25 to vi.
4202.198	.032	*b* 1	.166	.167½	1:8, 0.33 to vi.
04.101	.986	*b* 3	.115	.116	4:3, 0.06 to red; 2:3, 0.37 to vi.
10.494	.360½	*c* 5	.133½	.137	3:4, 0.07 to red; 1:4, 0.51 to vi.
16.351	.186	*b* 3	.165	.166	5:3, 0.65 to vi.; and faint lines on each side. Neutral
27.606	.444½	*d* 5	.161½	.168½	20:4, 0.70 to vi.; 1:4, 0.13 to vi.
33.772	.615	*d* 5	.157	.163	4:6, 0.44 to vi.
36.112	.950	*d* 5	.162	.168	Only lines 1:8 near
47.591	.443	*c*?	.148	.144	5:4, 0.60 to vi.; 1:4, 0.13 to vi. Group uncertain
50.287	.133	*c* 5	.154	.160	8:8, 0.66 to red; 2:8, 0.49 to vi.
50.945	.791½	*b* 2	.153½	.155	8:8, 0.66 to vi.
60.640	.487	*c* 2	.153	.156	3:10, 0.36 and 2:10, 0.49 to vi. Indeterminate?
71.934	.764	*b* 1	.170	.171½	6:15, 0.61 to vi.
82.565	.408	*b* 1	.157	.158	2:5, 0.44 to vi.; 4:5, 0.60 to red
91.630	.472	*a*	.158	.159	2:2, 0.35 and 1:2, 0.26 to vi.
94.301	.131½	*b* 2	.169½	.171	2:5, 0.10 to vi.
99.410	.251	*d* 5	.159	.165	3:4, 0.26 to vi.; 2:4, 0.39 to red
4308.081	.909	*b* 1	.172	.173	3:6, 0.17 and 2:6, 0.36 to vi.; 1:6, 0.25 to red
15.262	.089	*b* 3	.173	.174	3:4, 0.12 to vi.
25.939	.768	*b* 1	.171	.172	1:8 on each side. Neutral
37.216	.052	*b* 3	.164	.165½	3:5, 0.51 to red
52.908	.741	*b* 3	.167	.168	No companion
69.941	.776½	*b* 3	.164½	.166	1:4, 0.37 to vi.
76.107	.934	*a* 3	.173	.174	No companion
83.720	.548	*b* 1	.172	.173½	No companion
4404.927	.753	*b* 1	.174	.175½	Only 1:10 near
07.871	.716	*c* 4	.155	.158½	2:4, 0.06 to vi.; 2:4, 0.49 to red

TABLE I—*Continued*

λ_{Rowland}	$\lambda_{\text{I.A.}}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{\text{I.A.}}$ at 1 Atm	$\Delta\lambda'$ for $\lambda_{\text{I.A.}}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
4408.582	.420	*c* 4	.162	.165½	2:3, 0.22 to vi.; 2:3, 0.10 to red. Indeterminate
15.293	.127	*b* 1	.166	.167	2:8, 0.25 to vi.; 3:8, 0.43 to red. Probably neutral
22.741	.571	*b* 3	.170	.171	No companion
27.482	.314	*a* 3	.168	.169	2:5, 0.22 to vi.
30.785	.621½	*c* 4	.163½	.166½	1:3, 0.43 to vi.; 0:3, 0.14 to red. Neutral
42.510	.347	*c* 4	.163	.166	1:6, 0.49 to red. Neutral
43.365	.198	*b* 3	.167	.168	1:3, 0.37 to vi.; 5:3, 0.61 to red
47.892	.725	*c* 4	.167	.170	No companion
54.552	.386	*b* 3	.166	.167½	5:3, 0.40 to red
59.301	.126	*c* 4	.175	.178	2:3, 0.10 to vi.; 1:3, 0.22 to red. Indeterminate
61.818	.657	*a* 3	.161	.162	3:4, 0.35 to red; 1:4, 0.45 to vi.
66.727	.556	*b* 4	.171	.172	1:5, 0.37 to red
76.185	.024½	*b* 4	.160½	.162	3:4, 0.07 to red
89.911	.745	*a* 3	.166	.167	3:4, 0.34 to red
94.738	.572	*c* 4	.166	.169½	No companions
4528.798	.622½	*c* 4	.175½	.179	No companions
31.327	.155	*b* 3	.172	.174	2:5, 0.20 to vi.; 2:5, 0.47 to red
48.024	.853	*c* 4?	.171	.175	No companion
56.306	.131	*e*	.175	.171	3:4, 0.24 to vi.
92.840	.658	*c* 4?	.182	.186	2:4, 0.13 to vi.
4603.126	.947	*c* 4?	.179	.183	No companion
25.227	.059	*d*?	.168	.176	No companion
37.685	.519½	*d*?	.165½	.173½	4:5, 0.51 to red
47.617	.439	*c* 4?	.178	.182	Only very faint companion
68.331	.150	*d*?	.181	.189	2.4, 0.09 to vi.; 1:4, 0.42 to red
79.027	.856	*c* 4	.171	.175	2:6, 0.38 to red
91.602	.417	*c* 4	.185	.189	1:5 on each side. Probably neutral
4707.457	.288	*c* 5	.169	.167	2:5, 0.22 to red
27.582	.410	*d*?	.172	.180	2:3, 0.09 to red
27.676	.464	....	.212	....	Mn; 3:2, 0.09 to vi.
36.963	.786	*c* 5	.177	.184	2:6, 0.58 to red. Probably neutral
83.613	.433	*c* 5	.180	.187	No companion
87.003	.811	*c* 4	.192	.196	3:2, 0.28 to vi.
88.952	.762½	*c* 4	.189½	.193½	2:3, 0.58 to red
89.849	.657	*c* 4	.192	.196	2:3, 0.32 to vi.
4823.697	.524	*c* 5	.173	.180	3:5, 0.63 to red. Neutral
59.928	.758	*c* 5	.170	.178½	30:4, 1.6 to red. Too distant
71.512	.333	*c* 5	.179	.188	3:5, 0.52 to vi.; 1:5, 0.60 and 4:5, 0.82 to red
72.332	.153	*c* 5	.179	.187½	1:4, 0.22 to vi.
78.407	.225	*c* 5	.182	.190	3:4, 0.09 to vi.
90.948	.769	*c* 5	.179	.187	8:6, 0.74 to red. Too distant
91.683	.507	*c* 5	.176	.183	6:8, 0.74 to vi.; 1:8, 0.35 to red
4903.502	.325	*c* 5	.177	.184½	Only 0:5, 0.06 to vi.
19.174	.007	*c* 5	.167	.175	2:6, 0.63 to vi.
20.685	.518	*c* 5	.167	.174	No companion

TABLE I—*Continued*

$\lambda_{Rowland}$	$\lambda_{I.A.}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{I.A.}$ at 1 Atm	[Rowland − I.A.] $\Delta\lambda'$ for $\lambda_{I.A.}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
4924.956	.776	*a*	.180	.182	No companion
38.997	.827½	*c*	.169½	.175	2:4, 0.42 to red; 2:4, 0.65 to vi.
39.868	.689	*a*	.179	.181	2:3, 0.45 to vi.
57.480	.310½	*c* 5	.169½	.176	8:5, 0.30 to red
57.785	.610	*c* 5	.175	.183	5:8, 0.30 to vi.
66.270	.104	*c* 5	.166	.174	No companion
78.785	.614½	*c*	.170½	.176	0:3, 0.05 to vi. Probably too faint
82.682	.526	*d*	.156	.166	2:4, 0.31 to red
85.432	.268	*c*	.164	.170	3:3, 0.30 to red
85.730	.562	*c*	.168	.176	3:3, 0.30 to vi.
94.316	.134	*a*	.182	.182½	No companion
5002.044	.881	*c*	.163	.171	No companion
05.896	.728½	*c*	.167½	.176	5:4, 0.41 to red
06.306	.134	*c*	.172	.180	4:5, 0.41 to vi.
12.252	.073	*a*	.179	.179½	1:4, 0.08 to red
15.123	.959½	*c*	.163½	.171½	3:3, 0.67 to vi. Too distant
22.414	.253	*c*	.161	.169	No companion
28.308	.132½	*a*	.175½	.177½	1:2, 0.37 to vi.
41.255	.078	*a*	.177	.179	3:4, 0.19 to vi.; 2:4, 0.54 to red
41.936	.762	*a*	.174	.176	2:4, 0.14 to vi.; 1:4, 0.43 to red
50.008	.827	*a*	.181	.183	No companion
51.825	.641	*a*	.184	.186	1:4, 0.14 to vi.; 0:4, 0.26 to red
65.207	.016	*e*	.191	.183	1:3, 0.06 to vi.; 2:3, 0.17 to red
68.944	.782	*c*	.162	.170	No companion
74.932	.747	*e*	.185	.181½	No companion
79.409	.228	*a*	.181	.183	3:4, 0.25 to vi.; 4:4, 0.51 to red
79.921	.742½	*a*	.178½	.180½	4:4, 0.51 to vi.; 1:4, 0.22 to red. Probably neutral
83.518	.344	*a*	.174	.175½	No companion
97.175	.992	*e*	.183	.179	0:3, 0.14 to vi. Too weak?
98.885	.706	*a*	.179	.181	1:3, 0.13 to vi; 0:3, 0.37 to red
5107.619	.454	*a*	.165	.167	4:4, 0.20 to red
07.823	.646	*a*	.177	.179	4:4, 0.20 to vi.
10.574	.415	*a*	.159	.161½	No companion. Double in sun?
23.899	.727½	*a*	.171½	.173½	No companion.
25.300	.137	*d*	.163	.176	1:3, 0.12 to red
27.533	.364	*a*	.169	.171	No companion
33.870	.672½	*e*	.197½	.187½	No companion
39.427	.269	*c*	.158	.167	4:4, 0.22 to red
39.644	.482	*c*	.162	.171	4:4, 0.22 to vi
51.020	.846	*a*	.174	.176	No companion
52.087	.917	*a*	.170	.172	0:3, 0.27 to red
62.449	.319	*d*	.130	.160	No companion
67.678	.492	*a*	.186	.187½	15:5, 0.18 to vi.
91.629	.473	*c*	.156	.165	No companion
92.523	.363	sub-*d*	.160	.171	2:5, 0.62 to red
95.113	.950	*a*	.163	.165	2:4, 0.53 to red
95.647	.472	*e*	.175	.171½	4:2, 0.53 to vi; 1:2, 0.58 to red
5202.516	.342	*a*	.174	.176	2:4, 0.08 to vi.
08.596	.429	....	.167	....	*Cr;* 2:5, 0.18 to red

TABLE I—*Continued*

λ_{Rowland}	$\lambda_{\text{I.A.}}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{\text{I.A.}}$ at 1 Atm	[Rowland − I.A.] $\Delta\lambda'$ for $\lambda_{\text{I.A.}}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
5208.776	.611	sub-*d*	.165	.176	5:2, 0.18 to vi.
15.353	.197	sub-*d*	.156	.167	No companion
16.437	.279	*a*	.158	.160	No companion
17.552	.406½	*c*	.145½	.154½	No companion
27.043	.878	*c*	.165	.174	2:3, 0.34 to vi.; 5:3, 0.32 to red. Indeterminate
27.362	.190	*a* 4	.172	.174	3:5, 0.32 to vi.
30.030	.864	*c*	.166	.175	No companion
33.122	.957	sub-*d* 5	.165	.176	No companion
42.658	.496	*a*	.162	.164	No companion
63.486	.320	sub-*d*	.166	.176	No companion
66.738	.569	sub-*d* 5	.169	.180	No companion
69.723	.540	*a* 1	.183	.185	No companion. Double in sun?
70.558	.358	*a* 4	.200	.202	3:4, 0.12 to vi.
73.339	.178	sub-*d*	.161	.173	2:3, 0.22 to red
73.558	.380	sub-*d*	.178	.190	3:2, 0.22 to vi.
81.971	.804	sub-*d*	.167	.179	No companion
83.802	.634	sub-*d*	.168	.180	1:6, 0.48 to red. Neutral
5302.480	.315	sub-*d*	.165	.177	No companion
24.373	.196	sub-*d* 5	.177	.184½	No companion
28.236	.044	*a* 1	.192	.194	2:8, 0.28 and 2:8, 0.51 to red. Double in sun?
28.747	.538	*a* 4	.209	.210½	Doubtful. May be blend. Several to vi.
01.722	.538	....	.184	.185½	Blend?
33.089	.907	*a* 4	.182	.184	1:4, 0.24 to vi.
40.121	.946	sub-*d* 5	.175	.186	No companion
41.213	.030	*a* 4	.183	.185	1:7, 0.12 to red. Relatively too weak
65.069	.862	*e*	.207	.196½	3:5, 0.53 to red
65.596	.404	*a*	.192	.194	5:3, 0.53 to vi.
67.669	.455	*e*	.214	.204	No companion
70.166	.960	*e*	.206	.202	1:6, 0.38 to vi.
71.734	.495	*a* 1	.239	.241	4:3, 0.08 to vi.
73.905	.704	*e*	.201	.194	No companion
83.578	.366	*e*	.212	.205	No companion
93.375	.184	*d*	.191	.201	No companion
97.344	.135	*a*	.209	.211	1:7, 0.48 to red
5404.357	.131	*e*	.226	.220	2:5, 0.33 to vi.
05.989	.780	*a*	.209	.211	1:6, 0.44 to vi.
11.124	.903	*e*	.221	.211	1:4, 0.30 to red
15.416	.189	*e*	.227	.217	No companion
24.290	.055	*e*	.235	.223	No companion
29.911	.701½	*a*	.209½	.211½	1:6, 0.19 to vi.; 0:6, 0.15 to red
34.740	.527	*a*	.213	.215	No companion
45.259	.041	*e*	.218	.209	No companion
47.130	.921	*a*	.209	.211	2:6, 0.33 to vi.
55.834	.614	*a*	.220	.222	2:4, 0.16 to vi.
63.174	.962	*e*	.212	.207	3:3, 0.32 to red
63.494	.272	*e*	.222	.218	3:3, 0.32 to vi.

TABLE I—*Continued*

λ Rowland	λ I.A.	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{I.A.}$ at 1 Atm	$\Delta\lambda'$ for $\lambda_{I.A.}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
5476.500	.296	*a*	.204	.206	3:1, 0.28 to red
76.778	.581½	*d*	.196½	.202½	1:3, 0.28 to vi.; 5:3, 0.34 to red
97.735	.522	*a*	.213	.215	No companion
5501.683	.470½	*a*	.212½	.215½	No companion
07.000	.784	*a*	.216	.218	No companion
35.644	.420	*a*	.224	.226	2:2, 0.58 to vi.; 0:2, 0.13 to red
43.414	.183½	*e*	.230½	.222½	No companion
55.122	.881	*e*	.241	.233	No companion
62.933	.712	*e*	.221	.213	No companion
63.824	.610	*d*	.214	.225	0:3, 0.09 to red
65.931	.701	*e*	.230	.222	No companion
69.848	.633	sub-*d*	.215	.224	No companion
73.075	.858	sub-*d*	.217	.227	1:6, 0.25 to red
76.320	.107	sub-*d*	.213	.223	No companion
86.991	.772	sub-*d*	.219	.231	No companion
94.884	.661	*e*	.223	.214	4:1, 0.19 to vi.
98.524	.300	*e*	.224	.215	4:1, 0.19 to red
5603.186	.963	sub-*d*	.223	.234	3:4, 0.10 to vi.
15.877	.661	sub-*d*	.216	.228	2:6, 0.36 to vi.
24.769	.561	sub-*d*	.208	.220	1:4, 0.52 to vi.
38.488	.278	sub-*d*	.210	.220	No companion
5659.052	.836	sub-*d*	.216	.227	1:4, 0.30 to vi.
5975.575	.352	*b*	.223	.226	Only air line, 1:3, near
77.007	.806	*d*	.201	.218	Only faint air lines near
83.908	.707½	*d*	.200½	.217½	No companion
85.040	.807	*e*	.233	.223	No companion
87.290	.059½	*e*	.230½	.220½	No companion
6003.239	.039	*d*	.200	.217	No companion
08.186	.967	*e*	.219	.209	6:4, 0.60 to red
08.785	.585	*d*	.200	.217	4:6, 0.60 to vi. Relatively weaker
20.401	.177	*b?*	.224	.228	2:4, 0.17 to vi.
24.281	.060½	*e*	.220½	.210½	No companion
27.274	.059	*b*	.215	.219	No companion
42.315	.008½	*e*	.226½	.216½	No companion
56.227	.992	*e*	.235	.225	No companion
65.709	.492	*b*	.217	.222	No companion
78.710	.481	*e*	.229	.219	2:5, 0.52 to red
6136.829	.624½	*b*	.204½	.210½	3:8, 0.38 to red
37.915	.701	*b*	.214	.219	No companion
48.040	.839	*d*	.201	.219	2:3, 0.09 to vi.
51.834	.631	*d*	.204	.222	No companion
57.945	.732	*b*	.213	.216	No companion
73.553	.344	*b*	.209	.213	No companion
80.420	.217½	*d*	.202½	.220½	No companion
91.779	.568	*b*	.211	.216	6:9, 0.39 to vi.
6200.527	.322	*b*	.205	.210	No companion
13.644	.439	*b*	.205	.210	No companion
19.494	.289	*b*	.205	.210	No companion
30.943	.734	*b*	.209	.213	No companion
32.856	.665½	*d*	.190½	.209½	No companion

TABLE I—*Continued*

λ_{Rowland}	$\lambda_{\text{I.A.}}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{\text{I.A.}}$ at 1 Atm	[Rowland − I.A.] $\Delta\lambda'$ for $\lambda_{\text{I.A.}}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
6246.535	.343	*d*	.192	.209½	No companion
52.773	.567½	*b*	.205½	.210½	No companion
54.456	.267	*b*	.189	.193	1:5, 0.07 to vi.
56.572	.373	*b*	.199	.205	No companion
65.348	.145	*b*	.203	.207	No companion
98.007	.802	*b*	.205	.210	2:5, 0.66 to red
6301.718	.523½	*d*	.194½	.210½	Only distant air line, 2:7
02.709	.513	*d*	.196	.215	Only air line, 2:5 on each side
18.239	.028	*b*	.211	.216	No companion
35.554	.341	*b*	.213	.218	No companion
37.048	.845	*d*	.203	.219	No companion
93.820	.612	*b*	.208	.212	No companion
6400.217	.021	*d*	.196	.211	2:8, 0.32 to red
08.233	.042	*d*	.191	.211	No companion
11.865	.673	*d*	.192	.207	No companion
21.570	.362	*b*	.208	.212	No companion
31.066	.859	*b*	.207	.211	No companion
6495.213	.993	*b*	.220	.224	Only faint air lines, 1:8

because they are the only lines for which the effect of pressure can be approximately eliminated before applying the test for the effect which is under investigation.

Column 1 of Table I contains the wave-lengths from Rowland's Preliminary Table of Solar Spectrum Wave-Lengths. Column 2 gives the laboratory wave-lengths of the same lines, at atmospheric pressure, on the International system. The method by which these were derived will be given in detail below. The values $\Delta\lambda$ give the differences (column 1 − column 2). Column $\Delta\lambda'$ gives the corresponding differences of wave-lengths after the International wave-lengths have been reduced to a pressure of 0.5 atmosphere. The reason and details for this reduction will be given later. In the last column are given such detailed remarks as will enable judgment, for each line separately, as to whether it comes within the possible or probable influence of other lines.

For column 2, the International secondary standards were adopted without modification. In order to include additional lines on the International system, but lines which are not standards, a comparison was made between the wave-lengths of Burns,[1] obtained

[1] *Lick Observatory Bulletin*, No. 247 (1913).

near sea-level, and those of St. John and Ware,[1] obtained in Pasadena and on Mount Wilson. For the purposes of this comparison the lines were separated according to their behavior under pressure, using the classification of Gale and Adams[2] with the addition by St. John and Ware,[3] and only those lines common to the two observers were taken for which the *group* according to behavior under pressure was known. The results of this comparison are summarized in Table II. The unit is 0.001 angstrom. The sub-

TABLE II

Group and Class		Mean λ		(Pasadena – Burns)		(Mount Wilson – Burns)	
e		4332	5450	-2.7_{3}	-9.4_{24}	$+2.7_{3}$	$+1.0_{24}$
		5406		-11.1_{14}		$+0.6_{14}$	
		6026		-8.7_{7}		$+1.1_{7}$	
a	*a* 1, 3, 4	4987	5150	$+1.5_{11}$	$+0.4_{46}$	$+0.2_{8}$	$+0.6_{33}$
	a	5033		-0.7_{13}		-0.8_{10}	
	a	5174		$+1.1_{13}$		$+2.8_{11}$	
	a	5468		-1.0_{9}		-1.2_{4}	
b	*b* 1	4287	4750	-0.7_{10}	-0.3_{47}	-0.3_{7}	-0.2_{27}
	b 2	4272		-0.5_{2}		$+0.5_{2}$	
	b 3	4365		$+0.2_{10}$		-0.3_{7}	
	b 4	4359		$+0.7_{3}$		$+4.0_{1}$	
	b	5236		-0.4_{22}		-0.4_{10}	
c	*c* 2, 4	4556	4790	-0.7_{18}	-0.2_{33}	-1.4_{11}	-1.0_{25}
	c	5061		$+0.4_{15}$		-0.8_{14}	
c 5			4840		-1.7_{15}		-2.6_{8}
sub-*d*			5400		$+0.1_{22}$		-0.5_{12}
d	*d* 5	4249	5530	-2.5_{4}	$+5.0_{26}$	-2.0_{4}	-2.2_{26}
	d	5775		$+6.4_{22}$		-2.3_{22}	

scripts give the number of lines included in the means. The separation, in the individual groups, according to wave-length was made in order to see whether Gale and Adams' law of increase of pressure-displacement according to the cube of the wave-length (for Fe)

[1] *Astrophysical Journal*, **36**, 34, 1912; *ibid.*, **39**, 14, 1914; *Mt. Wilson Contr.*, Nos. 61 and 75.

[2] *Mt. Wilson Contr.*, No. 58; *Astrophysical Journal*, **35**, 15 and 31, 1912.

[3] *Mt. Wilson Contr.*, No. 61; *Astrophysical Journal*, **36**, 33, 1912.

applies to the differences under consideration here. The table does not show, with any degree of definiteness, such a relationship, and accordingly the results were combined into means irrespective of wave-length. Reference to this point will be made again farther on.

Evidently systematic differences exist between the wave-lengths of Burns and those of St. John and Ware. Burns (*op. cit.*, p. 28) had also made a comparison of his wave-lengths with the first list by St. John and Ware, and had drawn the following conclusions: "My measures are in good agreement with the values of St. John and Ware in the case of lines for which these observers find the same wave-length on Mount Wilson as in Pasadena. In cases where they find a difference between the mountain and sea-level, my measures are in excellent agreement with the wave-lengths found on the mountain, although my observations were made at sea-level." The progressive trend of the quantities in Table II, in both of the columns (Pasadena—Burns) and (Mount Wilson—Burns), seems to establish a fairly definite relationship between these systematic differences and pressure-shift. The relative shift between groups *e* and *d* is, for (Pasadena—Burns), 0.014 A, and, for (Mount Wilson—Burns), 0.003 A. This indicates, in regard to the effective pressures in the arcs, that Burns's arc was intermediate between the other two, and roughly about one-fifth of the way from that of Mount Wilson.

In order to account for this apparently anomalous result it seems necessary to take into account the internal pressure in the arc as well as the external (atmospheric) pressure. I quote from some recent work of Goos:

> My observations with different sorts of iron arcs now show that, with the same external pressure—atmospheric pressure—on plates from different parts of one and the same arc, further by change of current, arc length, etc., line-shifts occur which are of the same order of magnitude as those observed by St. John and Ware. I would like to offer as an hypothesis at this point that these shifts are due in part to pressure differences; that higher pressures prevail at the negative pole than in the middle of the arc and at the positive pole; and that with larger currents the pressure within the arc increases. This is because with larger currents more iron vaporizes, the vapor density becomes greater, and a pressure arises in the inner parts of the arc.[1]

[1] *Astrophysical Journal*, **38**, 141, 1913.

If the existence of such variations in the internal pressure of the arc be granted, then it follows also that even for the same observer moderate differences in the effective pressure for the separate spectrograms are possible, unless greater precautions are taken than have hitherto been considered necessary. As the entire region of spectrum under discussion here, and with the dispersion employed, requires not a single plate but a series of plates, moderate irregularities in the relative effective pressure differences between Burns and St. John and Ware might easily arise and thus disturb the smooth progression according to *group* in the differences (Pasadena —Burns) and (Mount Wilson—Burns), and in addition mask such effects as variation of pressure-shift as a function of the wave-length. In this fact, combined with the concentration in one or a few small regions of the spectrum, may also lie the real cause of the apparently marked separation of group sub-*d* from group *d* in Table II. In this connection it may be well to indicate another direction in which the accordance is incomplete. Table II gives for the relative displacement of group *e* to group *d* the ratio 3:2, while the measures of Gale and Adams give 2:3.

At present no criterion is available for adjusting the wave-lengths of Burns, Pasadena, and Mount Wilson to a standard effective pressure, and where the external pressure is 1 atmosphere. For the main purposes of this article no serious inaccuracy will be introduced by reducing the Pasadena and Mount Wilson wave-lengths to those of Burns as outlined in Table III, and in each case

TABLE III

Corrections Applied to Reduce to Burns

Group	Pasadena	Mount Wilson
a, *b*, *c*, and sub-*d*	.000	.000 A
e	+.009	−.001
d and *d* 5	−.005	+.002

combining with equal weights the mean of the values thus obtained for Pasadena and Mount Wilson with the wave-length obtained by Burns. As far as possible, lines of groups *e* and *d* will be employed only in an auxiliary way when used in combination with lines of groups *a*, *b*, and *c*.

Column $\Delta\lambda'$ in Table I was obtained as follows: On the basis of a previous investigation on Rowland's wave-lengths (not yet published) it was found that the pressure in the solar reversing layer in which the Fe Fraunhofer spectrum originates is 0.5 atmosphere, relative to an assumed pressure of 1 atmosphere for the I.A. secondary standards. That this relative pressure of 0.5 atmosphere is essentially correct will be amply established later in this article. The laboratory wave-lengths $\lambda_{I.A.}$ correspond approximately to a pressure, external to the arc itself, of 1 atmosphere. The effective total pressure to which they correspond is at present unknown, and, besides, it is probably not strictly uniform over the entire length of spectrum covered. An effective pressure of 1 atmosphere is the best preliminary assumption that can be made for $\lambda_{I.A.}$. These wave-lengths were reduced to a pressure of 0.5 atmosphere to render them approximately homogeneous with Rowland's wave-lengths in the sun—except for the systematic differences between the two systems. This was done by applying to each line for which Gale and Adams had indicated the amount of displacement for given pressures a correction equal to $+\frac{1}{2}\Delta$ per atmosphere for lines of group *e*, and $-\frac{1}{2}\Delta$ per atmosphere for lines of groups *a*, *b*, *c*, and *d*, Δ being regarded as without sign of its own. In cases where the $\frac{1}{2}\Delta$ per atmosphere for the individual lines could not be obtained directly from the measures of Gale and Adams, these quantities were taken from Table IV. The values in this table were derived from

TABLE IV

CORRECTIONS $\frac{1}{2}\Delta$ PER ATMOSPHERE

Group	λ 4000	λ 4350	λ 4700	λ 5000	λ 5300	λ 5650	λ 6000
e	+.003	+.004	+.005	+.006	+.007	+.009	+.010
a	−.001	−.001	−.002	−.002	−.002	−.003	−.003
b	−.001	−.001	−.002	−.002	−.002	−.003	−.004
c	−.002	−.003	−.004	−.005	−.006	−.007	−.009
c 5	. . . .	. . . .	−.007	−.008	. . . .	. . . .	. . . .
d and sub-*d* . .	−.005	−.007	−.008	−.010	−.012	−.015	−.017

the lines of known displacement, in part by actual means and for separate regions of the spectrum, and in part by the application, to the means, of the law of variation with the cube of the wave-length which was found for the iron spectrum by Gale and Adams.

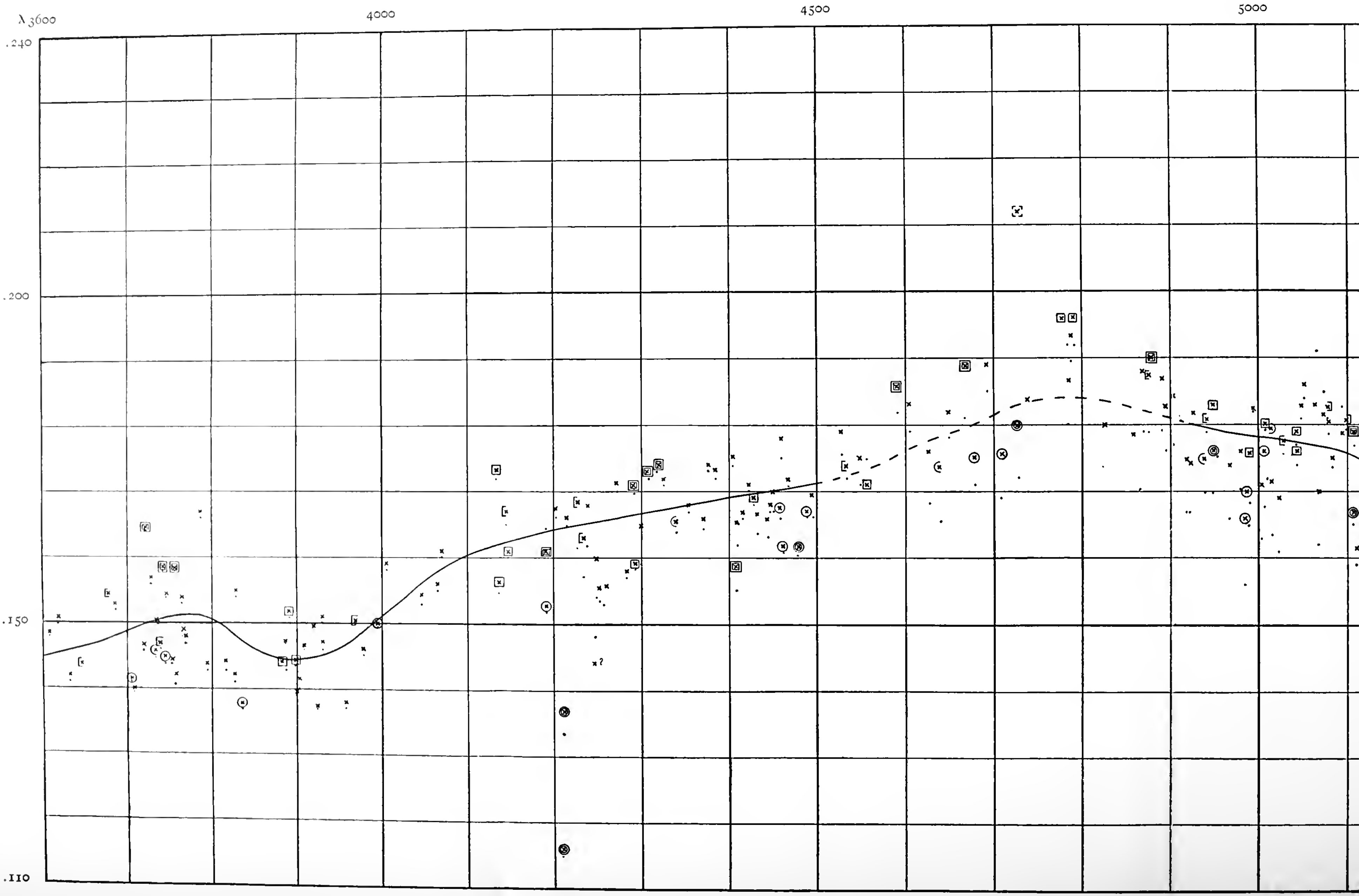

FIG. 1

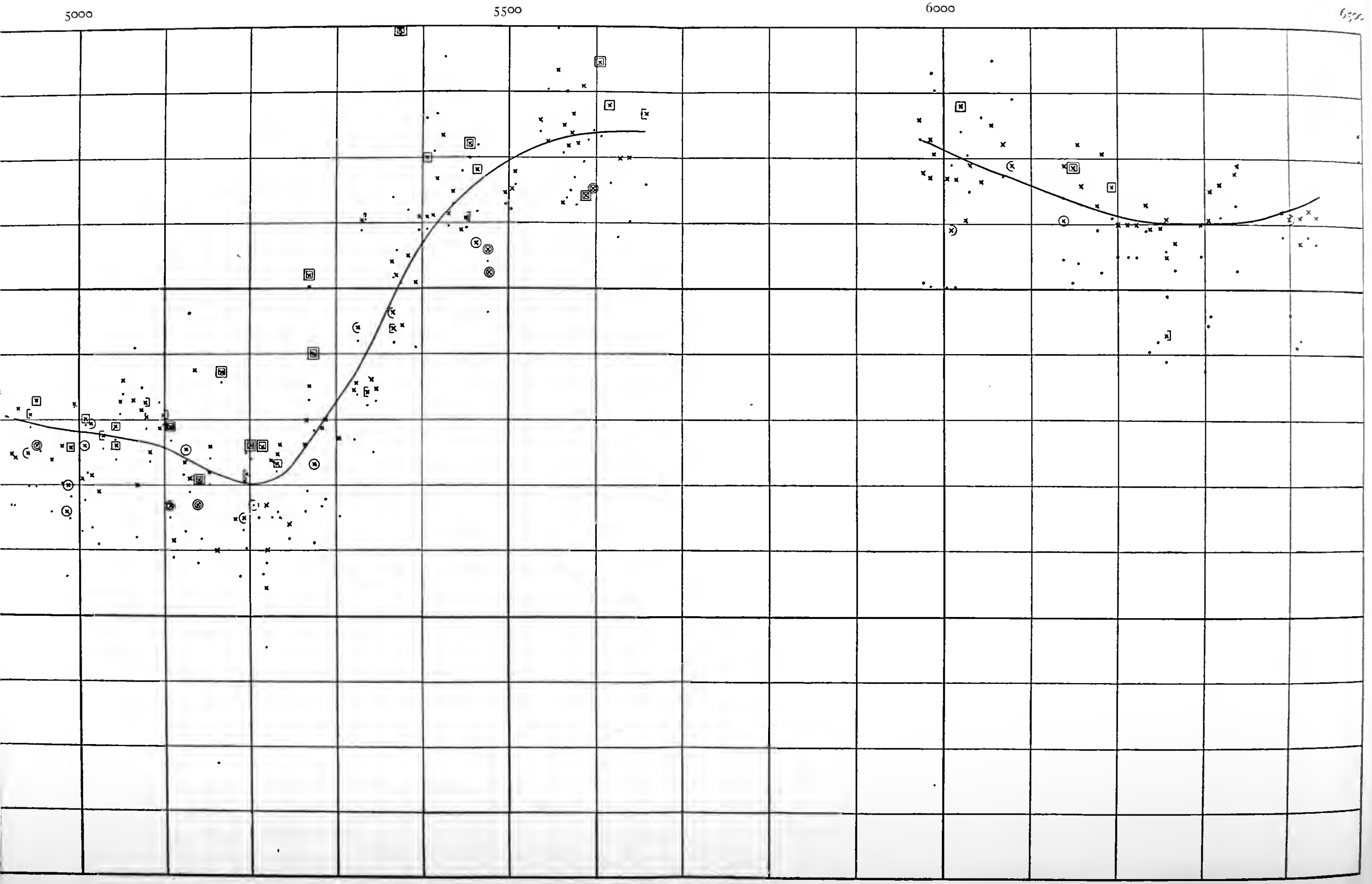

Fig. 1

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DERIVATION AND DISCUSSION OF RESULTS

The choice, from Table I, of the lines which should contain a Julius effect—if there is really such an effect—was made a separate piece of work in which no reference was made to columns $\Delta\lambda$ and $\Delta\lambda'$. In fact these two columns had been formed on a separate sheet, and thus one could not thereby be subconsciously influenced in the decision for or against the probability of a Julius effect. The lines selected are given in Tables V and VI, separated according as the companion line is toward the red or toward the violet in the solar spectrum. The actual basis on which this selection was made can readily be seen from the detailed remarks for each line in Table I. The companion lines need not necessarily be *stronger* lines, but must only be of *sufficient* strength and proximity. The essential requirement in making such selections is that the adopted principle of selection be reasonably definite, and that it be adhered to as rigidly as the conditions allow. At the conclusion of the investigat on the writer re-examined, in Rowland's tables, the lines listed in Table I in order to learn to what extent a choice made at that time would differ from the lists given in Tables V and VI. It was found that with the possible exception of two or three lines the identical selection would have been made.

The weights for the individual lines were assigned entirely on the basis of the intensities, the relative intensities, and the separation from the companion lines. For only two of the lines retained, λ 6008 and λ 4227, does the separation appreciably exceed 0.5 A. For the former it is 0.6 A, and the intensity of the companion line is 50 per cent stronger than that of the line; for the latter the separation and relative intensity of the companion line are respectively 0.7 A and 500 per cent. All lines with separation close to or greater than 0.5 A were placed in the class of smallest weight.

The systematic differences between the Rowland and the International systems,[1] for the iron spectrum, are obtained from a graph with wave-lengths as abscissae and the values $\Delta\lambda'$ as ordinates. Fig. 1 is a reproduction of this graph. The quantities $\Delta\lambda'$ are

[1] As the greater part of the material forming the basis for this article is taken from an investigation on the Rowland system, which has not yet been published, a more complete discussion of the systematic differences between the Rowland and the International systems is reserved for another article.

TABLE V

FE LINES WITH COMPANIONS TOWARD THE RED IN THE SOLAR SPECTRUM

λRowland	Ratio of Intensities (Comp. : Line)	Separation	Weight	To Reduce Point to Curve	Group	Remarks
		A		A		
3705.708..	2: 9	0.14	1	+.007	*a* 1	
3735.014..	4:40	0.47	½	+.004	*b* 1	Doubtful?
3743.508..	2: 6	0.12	1	+.006	*b* 1	
3834.364..	4:10	0.14	1	+.009	*b* 1	And 3:10, 0.36 to vi.
3997.547..	2: 4	0.09	1	+.001	*b* 4	And 1:4, 0.29 to vi.
4191.595..	3: 6	0.25	1	+.011	*a* or *b*	
4204.101..	4: 3	0.06	2	+.048	*b* 3	And 2:3, 0.37 to vi.
4210.494..	3: 4	0.07	3	+.027	*c* 5	
4337.216..	3: 5	0.51	½	+.002	*b* 3	
4454.552..	5: 3	0.40	1	+.003	*b* 3	
4461.818..	3: 4	0.36	1	+.008	*a* 3	And 1:4, 0.45 to vi.
4476.185..	3: 4	0.07	3	+.008	*b* 4	
4489.911..	3: 4	0.34	1	+.004	*a* 3	
4637.685..	4: 5	0.51	½	+.004	*d*?	
4679.027..	2: 6	0.38	1	+.005	*c* 4	
4707.457..	2: 5	0.22	1	+.006	*c* 5	
4727.582..	2: 3	0.09	2	+.003	*d*?	
4938.997..	2: 4	0.42	½	+.005	*c*	And 2:4, 0.65 to vi.
4957.480..	8: 5	0.30	2	+.003	*c* 5	
4982.682..	2: 4	0.31	1	+.013	*d*	
4985.432..	3: 3	0.30	1	+.009	*c*	
5005.896..	5: 4	0.41	1	+.002	*c*	
5012.252..	1: 4	0.08	½	−.002	*a*	
5107.619..	4: 4	0.20	2	+.008	*a*	
5125.300..	1: 3	0.12	1	−.002	*d*	
5139.427..	4: 4	0.22	2	+.006	*c*	
5195.113..	2: 4	0.53	½	+.006	*a*	
5208.596..	2: 5	0.18	0	+.003	......	Cr line; weight 0—"group" is unknown
5273.339..	2: 3	0.22	1	+.004	sub-*d*	
5328.236..	2: 8	0.28	½	−.007	*a* 1	Double in sun?
5365.069..	3: 5	0.53	½	.000	*e*	
5463.174..	3: 3	0.32	1	+.009	*e*	And 1:3, 0.47 to vi.
5476.500..	3: 1	0.28	2	+.011	*a*	
5476.778..	5: 3	0.34	2	+.015	*d*	And 1:3, 0.28 to vi.
5598.524..	4: 1	0.19	3	+.008	*e*	
6008.186..	6: 4	0.60	½	+.012	*e*	
6078.710..	2: 5	0.52	½	−.002	*e*	
6136.829..	3: 8	0.38	1	+.004	*b*	
6400.217..	2: 8	0.32	½	+.001	*d*	
Weighted mean				+.0094		
Sum of weights				45.5		
Straight mean				(+.005)		
Number of lines				38		

TABLE VI

FE LINES WITH COMPANIONS TOWARD THE VIOLET IN THE SOLAR SPECTRUM

λRowland	Ratio of Intensities (Comp. : Line)	Separation	Weight	To Reduce Point to Curve	Group	Remarks
		A		A		
3647.988..	4:12	0.43	½	+.002	*b* 1	
3680.069..	2: 9	0.25	½	−.007	*a* 1	And 2:9, 0.46 to red
3722.729..	3: 6	0.09	2	−.014	*a* 1	
3737.281..	5:30	0.22	½	+.003	*a* 1	
3746.058..	8: 6	0.34	2	−.008	*a* 1	
3748.650..	10: 1	0.24	3	−.008	*b* 1	And 1:1, 0.17 to red
3887.196..	3: 7	0.25	1	.000	*b* 1	
3888.671..	2: 5	0.11	1	−.008	*b* 1	And 2:5, 0.30 to red
3895.803..	3: 7	0.22	1	.000	*a* 1	
3969.413..	6:10	0.53	½	−.004	*b* 1	
4132.235..	2:10	0.14	1	−.012	*b* 1	And 3:10, 0.46 to red
4134.840..	3: 5	0.25	1	+.006	*b* 4	
4144.038..	4:15	0.47	½	−.005	*b* 1	
4147.836..	2: 4	0.33	1	+.002	*a* or *b*	
4191.843..	6: 3	0.25	2	+.003	*e*	
4227.606..	20: 4	0.70	½	−.004	*d* 5	And 1:4, 0.13 on same side
4233.772..	4: 6	0.44	½	+.002	*d* 5	
4291.630..	2: 2	0.35	1	+.007	*a*	And 1:2, 0.26 on same side
4294.301..	2: 5	0.10	2	−.005	*b* 2	
4308.081..	3: 6	0.17	2	−.006	*b* 1	And fainter line on each side
4315.262..	3: 4	0.12	2	−.007	*b* 3	
4407.871..	2: 4	0.06	2	+.011	*c* 4	
4427.482..	2: 5	0.22	1	.000	*a* 3	
4531.327..	2: 5	0.20	½	−.002	*b* 3	And 2:5, 0.47 to red
4556.306..	3: 4	0.24	1	+.002	*e*	
4592.840..	2: 4	0.13	2	−.010	*c* 4?	
4668.331..	2: 4	0.09	2	−.010	*d*?	
4727.676..	3: 2	0.09	0	−.029	......	Mn, weight 0—"group" unknown
4787.003..	3: 2	0.28	1	−.012	*c* 4	
4789.849..	2: 3	0.32	1	−.012	*c* 4	
4872.332..	1: 4	0.22	½	−.006	*c* 5	
4878.407..	3: 4	0.09	2	−.008	*c* 5	
4939.868..	2: 3	0.45	½	−.002	*a*	
4957.785..	5: 8	0.30	1	−.004	*c* 5	
4985.730..	3: 3	0.30	1	+.003	*c*	
5006.306..	4: 5	0.41	1	−.002	*c*	
5028.308..	1: 2	0.37	½	.000	*a*	
5041.255..	3: 4	0.19	1	−.002	*a*	And 2:4, 0.54 to red
5041.936..	2: 4	0.14	1	+.001	*a*	And 1:4, 0.43 to red
5079.409..	3: 4	0.25	½	−.006	*a*	And 4:4, 0.51 to red
5098.885..	1: 3	0.13	½	−.005	*a*	And 0:3, 0.37 to red
5107.823..	4: 4	0.20	2	−.004	*a*	
5139.644..	4: 4	0.22	2	+.002	*c*	
5167.678..	15: 5	0.18	3	−.016	*a*	
5195.647..	4: 2	0.53	½	−.001	*e*	And 1:2, 0.58 to red
5202.516..	2: 4	0.08	2	−.006	*a*	
5208.776..	5: 2	0.18	3	−.006	sub-*d*	

TABLE VI—*Continued*

λ Rowland	Ratio of Intensities (Comp. : Line)	Separation	Weight	To Reduce Point to Curve	Group	Remarks
		A		A		
5227.362..	3: 5	0.32	1	−.003	*a* 4	
5270.558..	3: 4	0.12	2	−.026	*a* 4	
5273.558..	3: 2	0.22	2	−.014	sub-*d*	
5333.089..	1: 4	0.24	½	+.005	*a* 4	
5365.596..	5: 3	0.53	½	+.003	*a*	
5371.734..	4: 3	0.08	3	−.042	*a* 1	
5404.357..	2: 5	0.33	1	−.012	*e*	
5447.130..	2: 6	0.33	½	+.003	*a*	Double in sun?
5455.834..	2: 4	0.16	2	−.007	*a*	
5463.494..	3: 3	0.32	1	−.002	*e*	
5594.884..	4: 1	0.19	2	+.009	*e*	Measured only by Burns with large probable error
5603.186..	3: 4	0.10	2	−.011	sub-*d*	
5615.877..	2: 6	0.36	1	−.004	sub-*d*	
5659.052..	1: 4	0.30	½	−.003	sub-*d*	
6020.401..	2: 4	0.17	1	−.008	*b*?	
6148.040..	2: 3	0.09	2	−.005	*d*	
6191.779..	6: 9	0.39	1	−.004	*b*	
6254.456..	1: 5	0.07	½	+.017	*b*	Doubtful
Weighted mean				−.0066		
Sum of weights				81.5		
Straight mean				(−.0041)		
Number of lines				64		

plotted as crosses. For purposes which will become evident later, the values Δλ are also plotted, being represented in the graph by dots. Of the crosses, those representing lines which have companions toward the red in the solar spectrum (Table V) are provided with a semicircle, a circle, or two concentric circles, according as the adopted weight is ½, 1, or 2 and greater, respectively. Similarly, lines with companions toward the violet in the solar spectrum (Table VI) are accompanied by half a square, an entire square, or two squares.

The curve in Fig. 1 (for the quantities Δλ′) represents the systematic difference, as adopted for this investigation, between the Rowland and the International systems. It was originally drawn to represent best the normal places formed from the lines of groups *a* and *b* alone, because these lines, being only slightly affected by pressure, may be regarded as practically independent of a moderate

uncertainty in the adopted pressure difference of 0.5 atmosphere between the two systems of wave-lengths. However, a later close inspection of the points showed that no material change in the position of the curve results when the lines of groups *c*, *d*, and *e* are also included.

To anticipate somewhat, two facts stand out quite prominently in the graph. First, the correction of the wave-lengths in the International system to a pressure of 0.5 atmosphere has brought in toward the curve the lines which are strongly affected by pressure—namely, those of groups *c*, *d*, and *e*. Without the application of these corrections, the lines of groups *c* and *d* are decidedly below the curve, and those of group *e* are above the curve. This "drawing in" of the points toward the curve is gratifying, as it shows that the reduction of the wave-lengths in the International system to a pressure of 0.5 atmosphere has made them practically homogeneous with Rowland's wave-lengths in the sun—except, of course, for the systematic differences between the two systems as represented by the curve. Secondly, the separation, to the two sides of the curve respectively, of the circles and squares is quite pronounced. It is also evident that this separation of the circles and squares from each other is not dependent upon any particular position of the curve.

Column 5 in Tables V and VI gives the corrections which must be applied to reduce the points $\Delta\lambda'$ to the curve. This column furnishes the evidence required for our problem.

Column 5 in Table V contains only four negative values and one zero in a total of 38 lines. This strong preponderance of positive quantities shows that lines which have companions toward the red in the solar spectrum are systematically shifted toward the violet. The weighted mean, +0.0094 A, may be somewhat too high. If we were to omit the abnormally large value of +0.048, and reduce to weight 1 the relatively large value of +0.027, we should obtain for the weighted mean the value +0.0069. It seems that 0.007 A may be a fair approximation to the true displacement toward the violet, at λ 5000, for a mean ratio of intensities of 3:4,[1] and a mean separation of 0.24 A.

[1] These are not actual means of intensities but merely relative values of the intensities of companion line and line.

Table VI shows with nearly equal certainty that solar lines having companions on their violet sides are shifted toward the red. The weighted mean is −0.0066 A. One value, −0.042, seems abnormally large. If this be omitted, the weighted mean reduces to −0.0052 A. Possibly 0.005 A may be not far from the true displacement toward the red, at λ 5000, for a mean ratio of intensities of 8:9,[1] and a mean separation of 0.21 A.

We note that the displacement is greater in amount when the companion is toward the red than when it is toward the violet. It will be recalled that this is one of the requirements of the anomalous-dispersion theory, and I judge that the relative values of the displacements in the two cases are about what would be expected. The displacements being appreciably smaller for companion toward the violet would also account for the fact that in this case 26 per cent of the lines give values of opposite sign from the mean, while for companion toward the red only 11 per cent have opposite sign.

The weights which were assigned to the individual lines may be regarded as in part a measure of the certainty with which the Julius effect should be shown according to separation and ratio of intensities, and in part as a very rough indication of the magnitude of the effect. Naturally we should expect the displacement to be greater when the separation is small than when it is large. So also the certainty of such an effect (if it exists at all) is greater when the companion line is relatively the stronger. At the same time it is quite evident from Tables V and VI that the effect shown is not dependent upon the adopted system of weighting.

When the lines are grouped according to the separation from their companions and the direct means taken, we obtain the results given in Table VII. The subscripts indicate the number of lines

TABLE VII

MEANS—DISPLACEMENT ACCORDING TO SEPARATION FROM COMPANION

LINES WITH	SEPARATION		
	0.0 to 0.2 A	0.2 to 0.4	0.4 and Greater
Companion toward the red	$+.0103_{11}$	$+.0065_{17}$	$+.0036_{10}$
Companion toward the violet	$-.0073_{24}$	$-.0024_{31}$	$-.0010_{9}$

included in each mean. The decreasing displacement with increasing separation is quite definitely shown and justifies, a posteriori, the increased weight with diminished separation. For the lines with companions toward the red the mean separations are respectively 0.11, 0.30, and 0.49 A, and for the lines with companions toward the violet, 0.12, 0.28, and 0.50 A. If the values in Table VII are plotted as ordinates, with the mean separations as abscissae, we obtain curves *a* and *b* in Fig. 2. These curves represent first approximations of the relations between the amount of displacement and the separation of the line from its companion. Curve *a* gives the amount of displacement toward the violet, for separations

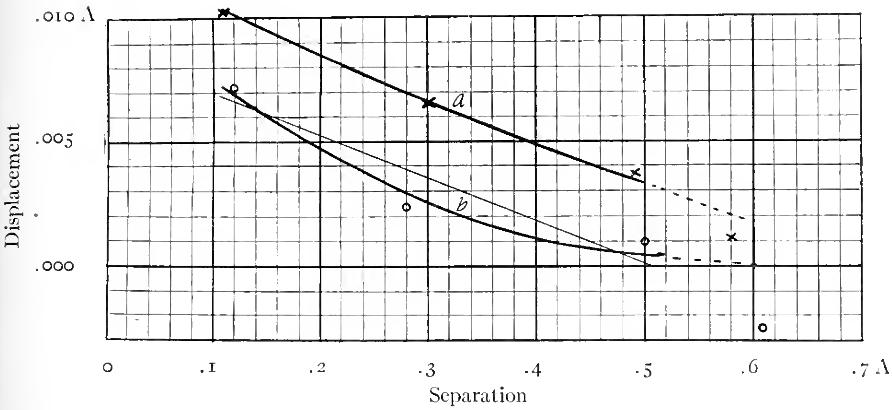

FIG. 2.—Displacements according to separation from companion

between 0.1 and 0.5 A, for lines which have companions toward the red. Curve *b* gives, for lines with companions toward the violet, the amount of displacement toward the red, between the same limits of separation. An extrapolation of the curve toward the right indicates that we may expect the effect of companion lines to be inappreciable at separations of 0.7 A and greater. With a view to determining roughly these extrapolated portions of the curves, Table I and Rowland's table were gone over again and additional lines were selected with separations between 0.5 and 0.7 A. The values thus obtained are plotted in Fig. 2 at 0.58 and 0.61 A. These must be regarded as quite uncertain, but if

given any weight at all, they would indicate that the Julius effect becomes inappreciable at a somewhat smaller limit than 0.7 A, especially for lines with companions toward the violet. It seems not improbable that for large separations both the intensity and the relative intensity of the companion line become relatively more important factors. In the near future we may expect a sufficient amount of additional material to become available to warrant making a closer approximation of the quantitative relation between displacement on the one hand and separation and intensities on the other.

As in Tables V and VI, so also in Table VII, the displacements are smaller in amount (disregarding signs) when the companion line is toward the violet than when it is toward the red. In Table VII this is seen to be true within each of the limits of separation.

In Table VIII are given the displacements, taken from column 5 of Tables V and VI, separated according to pressure groups. This table gives, both in the division for lines with companions toward the red and in that with companions toward the violet, a mean displacement which is practically the same for all groups. This shows that, first, the preliminary value of 0.5 atmosphere which was found for the pressure in the reversing layer of the sun where the Fe lines originate, and, secondly, the pressure displacements per atmosphere (in the mean) which were found by Gale and Adams, are close approximations to the correct values. It was the writer's original intention to make a second approximation of the pressure in the solar reversing layer at the conclusion of this investigation, but in view of the good agreement found above, this seems unnecessary at the present time, especially as additional material may be expected to become available in the near future.

The evidence adduced above is quite definite as to the observed facts. These are: Fraunhofer's lines, as given in Rowland's tables, are displaced when they have close companions; the displacement is (*a*) toward the violet when the companion line is toward the red, and (*b*) toward the red when the companion is toward the violet. The displacement in (*a*) is greater than in (*b*), and in both it increases as the separation between the lines diminishes. This effect appears to be due to anomalous dispersion, and conforms very

closely with the theoretical requirements as developed by Julius. One other possible cause that suggested itself to the writer is personality in the measurement of close pairs of lines. From the writer's own experience in measurement this did not seem probable. In order to gather further evidence along this line from other observers, St. John and Ware's[1] table of close pairs of lines was

TABLE VIII

FROM TABLES V AND VI, SEPARATED ACCORDING TO *Group* (IN UNITS OF 0.001 Å)

	With Companions toward the Red					With Companions toward the Violet				
	a	*b*	*c*	*d*	*e*	*a*	*b*	*c*	*d*	*e*
	+ 7	+ 4	+ 5	+ 4	0	− 7	+ 2	+11	− 4	+ 3
	+ 8	+ 6	+ 5	+ 3	+ 9	−14	− 8	−10	+ 2	+ 2
	+ 4	+ 9	+ 9	+13	+ 8	+ 3	0	−12	−10	− 1
	− 2	+ 1	+ 2	− 2	+12	− 8	− 8	−12	− 5	−12
	+ 8	+11	+ 6	+15	− 2	0	− 4	+ 3	− 6	− 2
	+ 6	+48	+27	+ 1		+ 7	−12	− 2	−14	+ 9
	− 7	+ 2	+ 6	+ 4		0	+ 6	+ 2	−11	
	+11	+ 3	+ 3			− 2	− 5	− 6	− 4	
		+ 8				0	− 5	− 8	− 3	
		+ 4				− 2	− 6	− 4		
						+ 1	− 7			
						− 6	− 2			
						− 5	− 8			
						− 4	− 4			
						−16	+17			
						− 6				
						− 3				
						−26				
						+ 5				
						+ 3				
						−42				
						+ 3				
						− 7				
						+ 2				
Means....	+4.4	+8.6	+7.9	+5.4	+5.4	−5.2	−2.9	−3.8	−6.6	−0.2
No. of lines	8	10	8	7	5	24	15	10	9	6

taken and corresponding columns added for Burns. An inspection of this table does not disclose any pronounced personal differences between the four observers in the measured differences of wavelength between the components of the pairs. Although, taken by itself, this does not entirely remove personality in Rowland's measures as a possible cause, it nevertheless places the chances

[1] *Astrophysical Journal*, **39**, 23, 1914.

against this as the cause. However, the principal objection is that it would be especially difficult to explain, on this ground, the observed inequality of the displacements for the two components.

It will be recalled that the investigation by Julius and St. John (*op. cit.*) on St. John's measures of the Evershed effect led to opposite conclusions as to the presence in those measures of an effect due to anomalous dispersion. Julius found that such an effect was superimposed upon the Evershed effect. By a different choice of lines and a somewhat different treatment of the data St. John found that the Julius effect vanishes. It was thought of interest to apply to the lines which were chosen by Julius and added by St. John (without referring to St. John's complete original list) the conditions of selection which were used in the present investigation. When this was done and those lines were eliminated which are indeterminate, the results summarized in Table IX were obtained. St.

TABLE IX

CHANGE IN THE EVERSHED EFFECT

Companion to Red				Companion to Violet			
38 original,	Σ weight	47	−.0026	34 original,	Σ weight	44	+.0012 A
19 additional	"	19	+.0019	17 additional	"	20	−.0011
Weighted mean,	"	66	−.0013	Weighted mean,	"	64	+.0005

John's residuals were used for this purpose. The final weighted means for companion to red and companion to violet are in the direction required by the Julius effect, though the numerical values are so small that they cannot—taken by themselves—be accepted as a definite indication of the effect.

SUMMARY AND CONCLUSIONS

According to the theory of anomalous dispersion as developed by Julius, Fraunhofer lines which are separated from each other by only very short distances (about 0.5 A or less) should produce mutual displacements of the lines, the violet and red components of a pair being displaced in opposite directions, the former somewhat more than the latter. Rowland's Preliminary Table of Solar Spec-

trum Wave-Lengths forms a suitable basis with which to make a test for this effect. In the test made (which is necessarily preliminary, the Fe lines alone were employed, the chief reasons for thus restricting the data being the following: (*a*) For these lines well-determined laboratory wave-lengths are available for the necessary comparisons. (*b*) As spectrum lines are affected selectively by pressure and as it is desirable to eliminate the unequal pressure effects, the data were further restricted to those Fe lines which had been classified according to pressure-shifts.

The principal results derived are: Lines with close companions toward the red in the solar spectrum are shifted toward the violet, and lines with close companions toward the violet are shifted toward the red. The displacement varies in amount with the separation of the lines, though for all separations it is greater when the companion line is toward the red than when it is toward the violet of the line. For a mean separation of 0.22 A the displacements are respectively 0.007 A and 0.005 A. These facts are in accord with the requirements of Julius' theory, and they seem definitely to establish the operation of anomalous dispersion in the sun.

Additional results and conclusions are: (1) A method is developed by which Rowland's Preliminary Table of Solar Spectrum Wave-Lengths is made available for comparison of solar wave-lengths with the best recent laboratory wave-lengths. As was also shown by Gale and Adams, Rowland's tables of wave-lengths are still too valuable to be discarded. By the development of a method of connecting laboratory wave-lengths with solar wave-lengths, both are made available for the study of various solar and stellar problems. (2) The Mount Wilson classification of spectrum lines according to behavior under pressure is confirmed. (3) It was shown that the pressure in the solar reversing layer where the Fe Fraunhofer lines originate is 0.5 atmosphere. (4) As a direct consequence of the progressive variation in intensity of lines in stellar spectra—some lines gradually disappearing and new lines coming in and increasing in strength as we proceed from type to type, thereby causing neighboring lines to change very markedly in relatively intensity, some lines gradually losing companions while others gain them—anomalous dispersion becomes *one* of the causes

producing the changes of wave-length which are progressive with the stellar spectral type.

This investigation shows (as was shown before) that the detailed study of spectrum lines according to their behavior under pressure marks a distinct step in stellar spectroscopy. When eventually standard wave-lengths are referred to a standard pressure, a long step will have been taken toward facilitating the problem of determining the pressure in stellar atmospheres, especially in the stellar spectral types A to M. This seems clearly foreshadowed owing to the differential separation—from a mean curve—of the lines of the different pressure groups when the pressure is varied. The process of determining the pressures will be similar to the processes that were employed in determining (*a*) the pressure in the solar reversing layer relative to that of the International secondary standards, and (*b*) the relative pressures in the arcs of Burns and of Mount Wilson and Pasadena.

Dudley Observatory
Albany, N.Y.
March 30, 1915

THE STARK EFFECT AND ATOMIC STRUCTURE

A CRITIQUE OF CERTAIN RECENT WORK

By GORDON S. FULCHER

In the autumn of 1913 Stark discovered that when certain spectrum lines are emitted in a strong electric field they are very markedly affected. A *low-dispersion spectroscope* shows Hα resolved into three polarized components, Hβ into four, Hγ into five, etc. The diffuse series of helium and lithium are also similarly analyzed. The relative position and intensity of the components as observed in a rough analysis are approximately indicated in Fig. 1. The *p*-components are polarized parallel to the field; the *s*-components at right angles to the field. Investigation made later by Stark with a very remarkable spectrograph combining considerable dispersion with great light-gathering power showed that the components just noted are all complex. The total number of components observed in this *fine analysis* varied from 18 to 28 for different H lines. The details will be presented later.

Since these spectrum lines are usually emitted in an electric field, it seems strange that the Stark effect has escaped detection for so long. In fact Lo Surdo did observe it immediately in front of the cathode in a capillary discharge tube, and the Lo Surdo arrangement is the most convenient for qualitative observations. But Stark's technical knowledge of canal-ray phenomena was necessary to overcome the experimental difficulty of securing the intense emission of light in a constant field of about 50,000 volts per cm, so that the effect could be studied quantitatively. To him and to his co-workers we owe most of our knowledge of the effect of an electric field on the frequencies of light emitted in it, and to him rightly belongs the honor of the association of the phenomenon with his name.

The extraordinary number of data accumulated during the eight months immediately following the discovery are summarized and discussed in the *Elektrische Spektralanalyse chemischer Atome*,[1]

[1] By J. Stark; 138 pp. and 4 plates (Leipzig: S. Hirzel, 1914).

which appeared last summer. The main experimental results are the following.

MAIN EXPERIMENTAL RESULTS

As in the case of the Zeeman effect, the polarization and number of the components depends on whether we look along the field or at right angles to it. The case where the direction of observation is perpendicular to the field is the more important and is called the "transverse effect." The other is the "longitudinal effect."

A. TRANSVERSE EFFECT

1. *Diffuse series of H, He, and Li.*—*a*) Polarization of components: The components polarized along the field (p-components) and those polarized at right angles (s-components) do not agree in number, position, or relative intensity in the case of H, but correspond more closely in the case of He and Li (see Fig. 1).

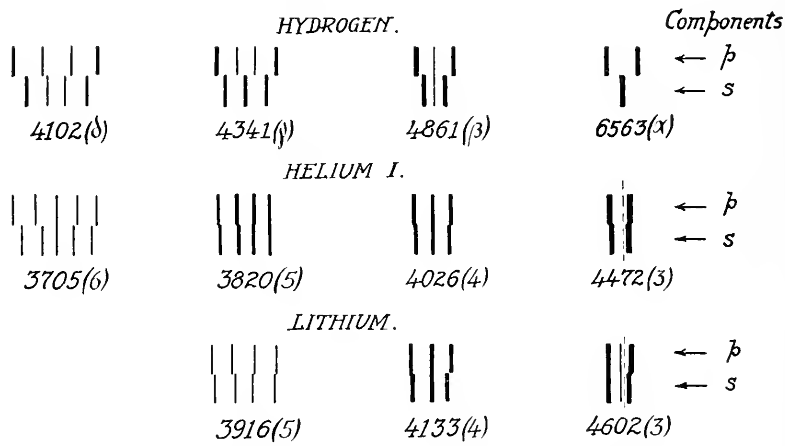

FIG. 1.—Stark effect for various series-lines. Rough analysis

b) Separation of components as a function of field-intensity: Measurements on H and He lines show the separation to be directly proportional to the field.

c) Symmetry of position of components: For H, the components are symmetrical both as to displacement from the original line and as to relative intensity, in the case of light from sources at rest. When the light comes from moving sources (canal rays), the

long-waved components are more or less intense than the short-waved components, according as the field is in the same or opposite direction to the velocity of the sources. Some He and Li lines show a distinct asymmetry both as to displacement and intensity.

d) Resolution of various lines of the same series: Unlike the Zeeman effect, the Stark effect varies from line to line of the same series. Both the number of components and the maximum displacement of the outer components increase regularly with the term-number (see Fig. 1).

e) Relative behavior of corresponding lines of H, He, and Li. There is a rough similarity, especially for the *s*-components of all three, and for the *p*-components of He and Li (see Fig. 1).

2. *Other series of lines.*—*a*) Sharp main and subordinate series of He and Li: The effect is much smaller than for the diffuse series. The separation, however, increases with the term-number as for the other series.

b) Lines of other elements: Lines of Al, C, Ca, Hg, Mg, Na, and Th have been investigated. The effect was found to be small or practically nil. It appears that series lines of heavier elements are less affected than the corresponding lines of chemically similar elements of less atomic weight. The diffuse series of triplets of Hg show an appreciable effect.

3. *Band lines of H and N.*—*a*) Earlier observations showed no effect for these lines. Later, however, positive results were obtained for some H band or rather compound lines. Some of these lines are unaffected; others instead of being resolved into components are shifted either toward the red or toward the violet. This merely emphasizes the complexity of this spectrum, in agreement with Dufour's measurements of the Zeeman effect. Whether the shift is proportional to the field or increases more rapidly is as yet undecided.

B. LONGITUDINAL EFFECT

1. *Diffuse series of H and He.*—*a*) Components are unpolarized.

b) Components agree in displacement and relative intensity with the *s*-components of the transverse effect.

C. WIEN MAGNETIC EFFECT

An electric charge e moving in a transverse magnetic field of strength H, experiences the well-known Lorentz force $e\left[H\frac{v}{c}\right]$ which is perpendicular to both H and v, and is equivalent to an electric force. Wien observed the light emitted by canal rays in a strong magnetic field in a direction at right angles to the velocity of the rays and found a resolution into components precisely like that obtained by Stark with an equivalent electric field.

D. COMBINED STARK AND ZEEMAN EFFECTS

Croze investigated the Zeeman effect for $H\alpha$ in a capillary tube perpendicular to the axis of the magnet and got incomplete polarization and too great a separation of the outer components. These results Stark explains as due to a superposition of the two effects. The interesting fact is that the components were still clearly resolved. More recently Garbasso[1] reports that while Hα is resolved into three components by either an electric or a magnetic field alone, the effect of both combined is a separation into four components, two polarized along the field due to the electric field and two polarized at right angles, due to the magnetic field, the central component due to each being absent.

DETAILS REGARDING THE HYDROGEN COMPONENTS

The mean shift—relative change of frequency per unit field—and the relative intensity of each pair of corresponding components of the various hydrogen series lines have been computed from Stark's measurements and are given in Table I. The means for each pair alone need be considered because of the evident symmetry of the components both as to position and relative intensity. Corresponding measurements agree usually to within 4 per cent for shift and 10 per cent for intensity. In the accompanying figures (Figs. 2 and 3) the relative intensities are indicated by the relative diameters of the circles. Components of the different lines which apparently correspond to each other are numbered alike;

[1] *Physikalische Zeitschrift*, **15**, 730, 1914.

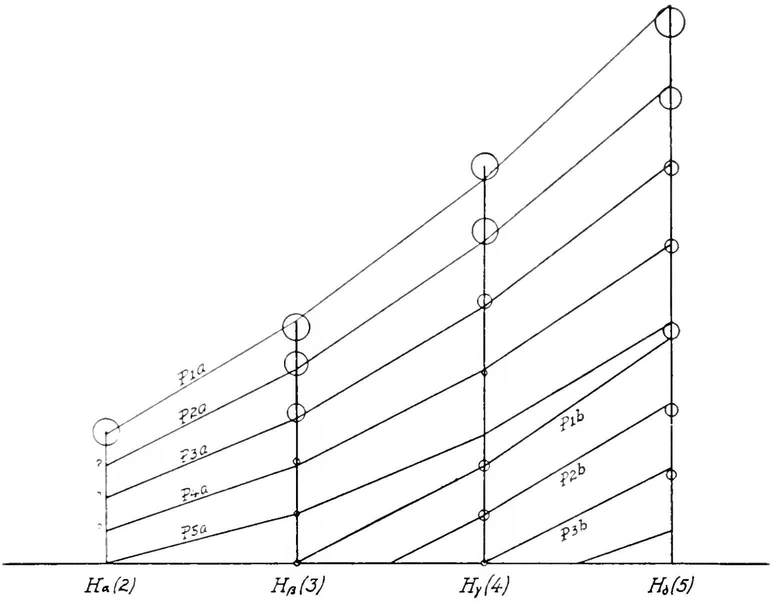

FIG. 2.—Components polarized parallel to the field. Fine analysis

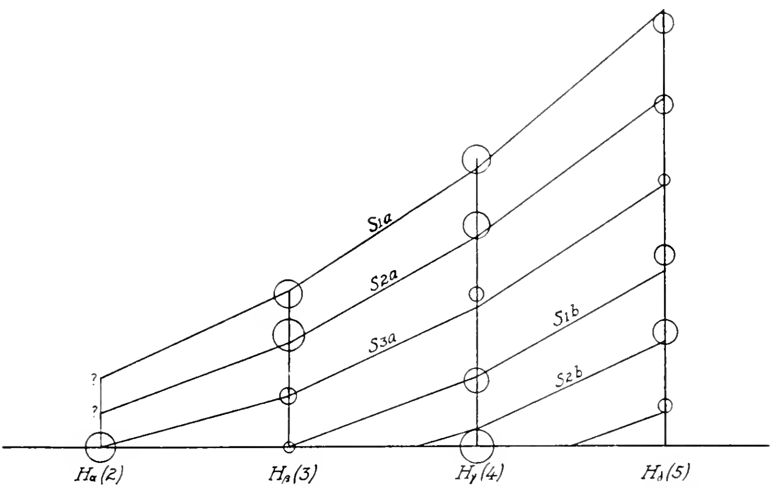

FIG. 3.—Components polarized perpendicular to the field. Fine analysis

those polarized parallel to the field are denoted by P; those polarized at right angles to the field are denoted by S. Two groups of P- and S-components are distinguished. The field actually used by Stark was 74,000 volts per cm and the maximum displacements obtained were 11A for Hβ, 17A for Hγ, and 22A for Hδ.

The fine analysis, as was stated above, resolves the few broad components of the rough analysis (shown in Fig. 1) into many more components. Thus the 26 components of Hδ (13 pairs) are blended together so that only 8 (4 pairs) are seen with low dispersion, one pair each for the Pa-, Pb-, Sa-, and Sb-components listed in Table I.

TABLE I

Component	$\frac{\Delta n}{nE}\times 10^8$			Relative Intensity		
	Hβ(4861)	Hγ(4340)	Hδ(4102)	Hβ	Hγ	Hδ
P1a........	3.14	5.30	7.21	1.75	1.77	1.90
2a........	2.66	4.43	6.22	1.56	1.63	1.40
3a........	2.00	3.50	5.28	1.06	0.79	0.75
4a........	1.35	2.53(?)	4.24	0.31	0.23	0.81
5a........	0.66	(?)	(?)	0.19	(?)	(?)
P1b........	0	1.31	3.11	0.10	0.55	0.97
2b........	....	0.64	2.06	....	0.58	0.83
3b........	....	0	1.18	....	0.33	0.67
S1a........	2.04	3.82	5.63	1.71	1.89	1.30
2a........	1.50	2.96	4.54	2.03	1.74	1.13
3a........	0.69	2.03	3.53	1.08	0.75	0.66
4a........	0	(?)	(?)	0.62	(?)	(?)
S1b........	....	0.88	2.54	....	1.56	1.22
2b........	....	0	1.52	....	2.18	1.52
3b........	....	....	.53	....	....	0.90

Some regularities are immediately evident.

1. The shift for the outer components (P1a) increases regularly with the term-number. Voigt suggested the formula

$$\frac{\Delta n}{nE}=A(m+1)^2\,; \tag{1}$$

and the formula

$$\frac{\Delta n}{nE}=B\,m(m+2) \tag{2}$$

also fits the observations quite closely, as shown in Table II.

2. The difference between the shifts of successive components ($P1a$, $P2a$, $P3a$, etc.) is approximately constant for each line,

TABLE II

Line and Term-Number	$H\alpha(2)$	$H\beta(3)$	$H\gamma(4)$	$H\delta(5)$	$H\epsilon(6)$	Mean
$\frac{\Delta n}{nE}$ (observed) $\times 10^8$	1.75	3.14	5.30	7.21	10.4	....
$\frac{\Delta n}{nE} \div (m+1)^2 \times 10^{-9}$	1.95	1.96	2.12	2.01	2.12	2.05
$\frac{\Delta n}{nE} \div m(m+2) \times 10^{-9}$	2.19	2.09	2.21	2.06	2.17	2.13

increases regularly from line to line with the term-number, and is roughly equal to $P1a$ divided by $(m+2)$, as shown in Table III.

TABLE III

	$H\beta(3)$	$H\gamma(4)$	$H\delta(5)$
$P1a-P2a$	0.48	0.87	0.99
$P2a-P3a$	0.66	0.93	0.94
$P3a-P4a$	0.65	0.97 (?)	1.04
$P1a \div (m+2)$	0.63	0.88	1.03

We have, then, apparently, $(m+2)$ Pa-components, spaced regularly at a distance of $0.213 \times 10^{-8}\, m$ apart. So our formula (2) above may be generalized to include all the Pa-components to

$$(Pa\text{-components})\ \frac{\Delta n}{nE} = 2.13 \times 10^{-9}[m(m+2) - m(p-1)] \qquad (3)$$

when p is the number of the component and varies from 1 to $m+3$.

3. Further investigation discloses similar regularities throughout. The positions of the components may all be represented within the apparently rather large experimental uncertainty, by the following equations, in which m stands for the term-number of the series line, and p and s each stand for the number of the component in a group of P- and S-components respectively.

Pa-components:

$$\frac{\Delta n}{nE}=2.13\times 10^{-9}[m(m+2)-m(p-1)] \tag{3}$$

$$\frac{\Delta n}{nE}=2.05\times 10^{-9}[(m+1)^2-m(p-1)] \tag{4}$$

Pb-components:

$$\frac{\Delta n}{nE}=2.13\times 10^{-9}[(m-3)(m+2)-(m-1)(p-1)] \tag{5}$$

$$\frac{\Delta n}{nE}=3.08\times 10^{-9}[(m-3)(m)-(m-2)(p-1)] \tag{6}$$

Sa-components:

$$\frac{\Delta n}{nE}=2.33\times 10^{-9}[m^2-m(s-1)] \tag{7}$$

$$\frac{\Delta n}{nE}=2.05\times 10^{-9}[(m-1)(m+2)-m(s-1)] \tag{8}$$

Sb-components:

$$\frac{\Delta n}{nE}=2.33\times 10^{-9}[(m-3)(m)-(m-1)(s-1)] \tag{9}$$

$$\frac{\Delta n}{nE}=3.08\times 10^{-9}[(m-3)(m-1)-(m-2)(s-1)] \tag{10}$$

The present data are not sufficiently accurate to decide between these alternative equations. For simplicity we should naturally choose either all the odd or all the even as then the number of constants is least and the equations are most closely related. To show how accurately the components may be represented by these equations, full lines have been drawn in Figs. 2 and 3 connecting points computed from the odd equations above, (3), (5), (7), and (9). This set of equations involves only two constants besides integers and gives the position of about forty components with fair approximation. An accurate investigation of the electric resolution of Hα and Hϵ would be interesting to determine whether the new data will fit into the foregoing equations or not.

COMPARISON OF THE EFFECT FOR CORRESPONDING H, He, AND Li LINES

Helium lines have also been studied carefully by Stark, but the results of the fine analysis have not been published. The corresponding $P1a$-components have shifts as given in Table IV. These may be represented by the following equations:

TABLE IV

MEAN $\frac{\Delta n}{nE}\times 10^8$

m	2	3	4	5	6
H	1.75	3.14	5.30	7.21	10.4
He I	Small(?)	1.63	3.36	5.20	8.4(?)
He II (parhelium)	Small(?)	1.84	3.63	(?)	(?)
Li	Small(?)	1.31	2.72	4.58	(?)

Hydrogen: $$\frac{\Delta n}{nE}=2.13\times 10^{-9}[m(m+2)] \quad (1)$$

Helium I: $$\frac{\Delta n}{nE}=2.66\times 10^{-9}[m(m-1)] \quad (11)$$

Helium II: $$\frac{\Delta n}{nE}=3.06\times 10^{-9}[m(m-1)] \quad (12)$$

Lithium: $$\frac{\Delta n}{nE}=2.24\times 10^{-9}[m(m-1)]^{1} \quad (13)$$

These equations merely serve to emphasize the similarity of the effect for these four diffuse series of lines.

Before considering the significance of these results in connection with atomic structure, Stark shows how this effect is probably related to two other spectral phenomena, (1) the broadening of lines in the case of great vapor- or current-density and (2) the pressure-shift.

RELATION TO THE BROADENING AND PRESSURE-SHIFT OF SERIES LINES

The very fact that it is the so-called "diffuse" series of H, He, and Li which show the Stark effect most markedly points to a

[1] The writer must assume all responsibility connected with the suggestion of equations (2) to (13). They seem obvious enough but are not given by Stark.

relation between broadening and the newly discovered effect. Broadening had not been studied quantitatively, so Wendt carried out a special investigation at Aachen and found that in any series of lines the broadening increases with the term-number in the same manner as the Stark effect. Stark also points out that the broadening is unsymmetrical in the case of those He and Li lines which show an unsymmetrical Stark effect. These facts strongly suggest that *broadening is due to the effect of the electric fields of neighboring atoms on those emitting the light.* However, broadening seems a much more common characteristic of lines than sensitiveness to an electric field, and special hypotheses have to be made to explain the small Stark effect in the case of lines such as the sodium D lines which are very easily broadened. Nevertheless, the suggestion of a relationship between the two phenomena must contain some truth and should prove very fruitful.

Stark also tries to connect the pressure-shift with the *asymmetry* observed in the electric resolution of some lines. In the case of Li and Hg the pressure-shift roughly corresponds, according to Stark, to what would be expected from the dissymmetry of the Stark-effect components as to position and relative intensity. This hypothesis is less firmly grounded than the preceding one, but should also prove stimulating to research in this field.

Astronomers immediately saw in the Stark effect a means of determining the electric fields of the sun and stars. Salet and Millochau, however, found no effect for $H\gamma$ in light from the chromosphere of the sun; and Stark points out how unlikely it is that in an ionized gas, not between electrodes, fields of the order of those used in his experiments should exist. The maximum field possible depends upon the pressure, so that greater fields may be expected in the lower layers of the sun's atmosphere. To study these, the Stark effect for iron and other metallic lines must be known.

Now as to the relation of the Stark effect to atomic structure. As Stark says, the importance of the effect lies in the fact that this relation is so intimate. Without a more or less definite hypothesis as to atomic structure, it cannot be understood at all. Its details are new facts to be explained, new and most important criteria for judging proposed atomic models; but the results are also

directly suggestive. The data have been summarized above; the suggestions are, briefly, the following.

1. *Asymmetry of intensity in the case of a moving source.*—Stark interprets this result as meaning that the electrons emitting the more intense component are on the forward end of the moving atom and emit more light as a result of collision with gas molecules than do electrons at the back end of the atom. If a train of waves is emitted by each electron, this involves the assumption that the position of the active electrons with respect to a plane perpendicular to the velocity of the canal rays is unchanged during the emission of any one component; that is, either they vibrate about fixed positions of equilibrium or they rotate in planes perpendicular to the velocity of the atom.

2. *Croze's results and the Wien experiments.*—The velocity of the electrons affected by the magnetic field consists of two parts, that due to the motion of the atom as a whole, and its velocity with respect to the atom. The latter is undirected with respect to the magnetic field. Stark argues from the fact that Croze obtained distinctly separated components (as did Garbasso also) that the speed of the electrons inside a hydrogen atom cannot exceed 10^6 cm per second. Further and more accurate observations on the combined Zeeman-Stark effect will prove most important if they lead to an accurate determination of this internal electronic speed.

3. *The number of hydrogen components.*—Stark is inclined to overemphasize the complexity of the analysis effected by an electric field. Yet, though the components are all probably quite simply related, their number and sharpness indicate that each hydrogen line may be emitted by an electron under more than a dozen distinct sets of circumstances—distinct at least in that they are differently affected by an electric field. Stark suggests a ring of electrons, each emitting the same line when the electric field is zero, each equally affected by a magnetic field, but each differently affected by an electric field. The sharpness of the components necessitates the assumption that the ring is fixed in orientation and that the emission of light is due to the vibration of the electrons about a position of equilibrium. But since the components are not independent, it does not seem that they each do demand a

separate electron as their source any more than the numerous band lines of nitrogen require an equal number of electrons in the nitrogen molecule. Yet the hydrogen atom must be a much more complex affair than any of the suggested atomic models.

The other important clues to atomic structure may now be mentioned as a basis for a brief summary of our present vague conception of the atom.

4. *Zeeman effect.*—This indicates that the emission of the series-lines associated with various elements is due to the acceleration of electrons in the atoms.

5. *Scattering of α and β rays by matter; production of very penetrating H rays by bombardment with α rays.*—Such experiments strongly support Rutherford's nuclear conception of the atom. Whether the deflection is due to the magnetic or to the electric forces associated with the nucleus, the concentration of the nucleus into an extremely small volume seems a necessary hypothesis. The charge computed for the nucleus comes out about $+\frac{1}{2}Me$, where M is the atomic weight.

6. *Characteristic X radiation.*—Moseley's results suggest that the fundamental characteristic atomic constant is the atomic number rather than the atomic weight. This atomic number increases by one as we pass from element to element in the periodic table and is probably equal to the nuclear charge measured in units equal in magnitude to the electric quantum.

7. *Doppler effect for canal rays.*—Stark has determined that the diffuse series of both hydrogen and helium I are emitted by atoms which have lost one electron, while the diffuse series of helium II (parhelium) is emitted by atoms which have lost two electrons. But a helium atom minus two electrons is an alpha particle; and it seems certain that an α ray is merely a helium nucleus unattended by detachable electrons. It seems clear, then, that *the nucleus must contain the electrons which emit the series lines.*[1]

While these clues are not at all conclusive, they suggest quite definitely the following vague picture of a hydrogen atom. A neutral hydrogen atom consists of a small nucleus with a charge

[1] This obvious conclusion from Stark's experimental results is, rather strangely, not mentioned by him.

$+e$, about which one electron revolves in dynamic equilibrium. Such a neutral atom cannot emit the Balmer series; it must first lose its electron by collision or otherwise. The Balmer series is emitted by electrons in the nucleus, vibrating about positions of static rather than dynamic equilibrium. Of the forces holding the parts of the nucleus together we know nothing except that apparently, according to Voigt, the forces involved are not isotropic, though they may be quasi-elastic. A swift electronic ray passing near the nucleus causes the emission of characteristic X radiation; while the shock of ionization results in the emission of light whose frequency may be affected by external magnetic and electric fields. Whether or not the nucleus contains magnetons we have no evidence upon which to base an opinion. When two atoms combine to form a molecule, the mutual influence of the nuclear fields changes the frequencies of vibration so that the spectrum emitted is quite different.

Now for the Bohr atom. How does it fare when tested by the Stark effect? Bohr does apparently succeed in relating the constant of the Balmer series to the Planck constant. But his assumption that the series lines are emitted by the single rotating electron of the hydrogen neutral atom is directly contrary to Stark's experimental result, which is one of the most certain clues we have. And as Stark says, such agreement with experiment as Bohr's theory does show "verliert ihre Bedeutung völlig dadurch, dass die Theorie wesentliche Züge der elektrischen Zerlegung der H-Serienlinien qualitativ nicht richtig wiederzugeben vermag" (p. 119).

In connection with the quantum theory in general, the following quotations may be of interest.

Als einer der ersten Anhänger der Planckschen Quantenhypothese möchte ich mir ihr gegenüber folgendes Bekenntnis erlauben. In mehreren Fällen scheint mir diese Hypothese in einem schwer lösbaren Widerspruch mit der Erfahrung zu stehen. Darum misstraue ich den Anwendungen, welche ich von der Planckschen Hypothese zur Deutung einiger Erscheinungen gemacht habe [p. 115]. . . . . Diese Folgerung über eine obere Grenze für die lichtschwingende Geschwindigkeit der Serienelektronen scheint mir eine ernsthafte Schwierigkeit für die Plancksche Lichtquantenhypothese mit sich zu bringen. . . . . Will man also die Plancksche Hypothese gegenüber der vorstehenden

Folgerung halten, so muss man eine weitere Hypothese zu Hilfe holen. . . . . Indes würde eine solche Hilfshypothese in meinen Augen mehr eine Belastung der Planckschen Hypothese mit Unerklärtheit bedeuten, und als Experimentalphysiker möchte ich dann lieber auf die Plancksche Hypothese selbst verzichten als so unbestimmte Hilfshypothesen in Kauf nehmen [p. 113].

In conclusion I should like to call the attention of theoretical physicists to the great field of unexplained intra-atomic phenomena to which the nuclear conception of the atom might be applied. Such investigation should lead either to a better understanding of such phenomena or to important modifications of the hypothesis or to both.

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April 16, 1915

THE TUBE-ARC SPECTRUM OF IRON AND A COMPARISON WITH DISSYMMETRIES IN SPARK SPECTRA[1]

By ARTHUR S. KING

In previous papers,[2] the writer has described some of the phenomena of the "tube-arc." To produce this light-source, the tube used in the electric furnace is filed thin at the middle of its length, so that when the voltage is applied, the tube quickly burns apart, forming an arc carrying a very large current at low voltage. The spectrum shows a high intensity of the enhanced lines of metals, the spark spectrum of carbon, and the brighter hydrogen lines, together with an interesting difference in the intensity of the lines of various elements across the diameter of the tube when this ring-shaped arc is viewed axially.

Another feature mentioned in the former papers is a marked dissymmetry in the structure of certain tube-arc lines. This was not studied in detail, but it was shown that the dissymmetry is very marked for many lines which are symmetrical in the furnace spectrum and approximately so in the ordinary arc in air.

Recently a much larger transformer was installed in the Pasadena laboratory, giving improved facilities for work with the tube-arc. Its capacity is 100 kw and the voltage may be varied by 5-volt steps from 5 to 50 volts. With this apparatus, tube-arcs have been operated which consumed as high as 70 kw just after the rupture of the tube. An initial energy of about 40 kw, however, has given the best results, the exposure being made while the current fell from above 1000 to about 600 amperes.

The second order of a 4-inch plane grating was used in the vertical spectrograph, with an objective of 30 feet focal length, giving a linear scale of about 1 mm=0.9 A. The interior of the tube, at the point where the arc was to form, was focused on the

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 103.

[2] *Mt. Wilson Contr.*, Nos. 65, 73; *Astrophysical Journal*, **37**, 119; **38**, 315, 1913.

slit, so that the spectrum registered the radiation along the vertical diameter of the ring of arc when the tube burned apart. The arrangement of the tube and the inclosing jacket of graphite was similar to that in the earlier experiments, except that the point of break was located by simply filing a deep groove around the tube at its middle. The gap between the ends of the tube, after the arc had ceased, usually measured 10–15 mm above and 30–40 mm below, but was occasionally longer. The time of action of the arc was generally 30–40 seconds.

The present paper will consider the leading features of the tube-arc spectrum of iron, these being, first, the displacements resulting from the dissymmetry shown by many of the stronger lines, the degree of this dissymmetry being clearly connected with the classification of the lines in the furnace spectrum and in that of other sources, and, second, the enhancement of certain types of lines. The peculiarities in structure of tube-arc lines are found to be very similar to those exhibited by the spectrum of the condensed spark. A comparison of typical iron lines in tube-arc and spark will be given, together with a brief description of the variable dissymmetries found in other spark spectra, especially that of titanium.

DISSYMMETRIES OF IRON LINES IN THE TUBE-ARC

A study of the tendency of various light-sources to render lines unsymmetrical has the twofold object of showing what features in the light-source produce these dissymmetries and the degree to which various lines are subject to such disturbing influences. The tube-arc shows effects in a very pronounced degree which are present in a more or less incipient state in the ordinary arc in air, especially in the region near the negative pole. Such dissymmetries are naturally most conspicuous in the case of reversed lines, and a large number of iron lines are given in reversal by the tube-arc. Few of these show a fully symmetrical reversal when their intensities are such that they are satisfactory for examination. A few low-temperature lines to the violet of λ 4000 reverse so widely in the tube-arc that they are practically absorption lines, and little can be said regarding the relative strength of their edges. The iron lines showing distinct self-reversal usually have the red side

stronger than the violet, and a large variability appears in the amount of the dissymmetry.

Lines of small or moderate dissymmetry toward the red.—In Table I, a list of lines is given whose dissymmetry of reversal does not

TABLE I

IRON LINES SHOWING SMALL OR MODERATE DISSYMMETRY TOWARD THE RED IN THE TUBE-ARC

λ (Rowland)	Ratio of Violet and Red Sides	Furnace Class	Pressure Class	Pressure Group
3887.196.....	2:3	I	1	*b*
3888.671.....	2:3	II (I)	1	*b*
3906.628.....	2:3	I	1	*b*
3969.413.....	3:4	II	1	*b*
4005.408.....	3:4	II	1	*b*
4045.975.....	3:4	II	1	*b*
4063.759.....	3:4	II	1	*b*
4071.908.....	3:4	II	1	*b*
4132.235.....	2:3	II	1	*b*
4144.038.....	3:4	II (I)	1	
4202.198.....	3:4	II	1	*b*
4250.945.....	3:4	II	2	*b*
4271.934.....	3:4	II	1	*b*
4282.565.....	5:6	I (II)	1	*b*
4294.301.....	5:6	I	2	*b*
4308.081.....	2:3	II	1	*b*
4325.939.....	2:3	II	1	*b*
4376.107.....	3:4	I	3	*a*
4383.720.....	2:3	II	1	*b*
4404.927.....	2:3	II	1	*b*
4415.293.....	2:3	II	1	*b*
4427.482.....	2:3	I	3	*a*
4461.818.....	5:6	I	3	*a*
5227.362.....	9:10	II	4	*a*
5269.723.....	9:10	I	1	*a*
5270.558.....	9:10	II	4	*a*
5328.236.....	9:10	I	1	*a*
5371.734.....	9:10	I	1	*a*
5397.344.....	9:10	I	4	*a*
5405.989.....	9:10	I	4	*a*
5429.911.....	9:10	I	4	*a*
5434.740.....	9:10	I	4	*a*
5447.130.....	9:10	I	4	*a*
5455.834.....	9:10	I	4	*a*

exceed a moderate amount, with the red side not more than twice as strong as the violet. Table II contains lines which reverse very unsymmetrically. Some of the latter show but a trace of the violet side of the line on the plate. The second columns of Tables I and II give the estimated ratios of the two sides of the reversal.

TABLE II

IRON LINES SHOWING LARGE DISSYMMETRY TOWARD THE RED IN THE TUBE-ARC

λ (Rowland)	Ratio of Violet and Red Sides	Furnace Class	Pressure Class	Pressure Group
4187.204.....	1:6	II (III)	....	....
4187.943.....	1:6	II (III)	....	....
4198.494.....	1:6	III	....	....
4227.606.....	1:8	III	5	*d*
4233.772.....	1:6	III	5	*d*
4236.112.....	1:6	II (III)	5	*d*
4250.287.....	1:6	III	5	*c*
4260.640.....	1:6	III	2	*c*
4271.325.....	1:6	III	....	....
4299.410.....	1:6	II	5	*d*
4528.798.....	1:4	II	4	*c*
4859.928.....	1:8	III	5	*c*
4871.512.....	1:8	III	5	*c*
4872.332.....	1:8	III	5	*c*
4890.948.....	1:8	III	5	*c*
4891.683.....	1:8	III	5	*c*
4919.174.....	1:8	III	5	*c*
4920.685.....	1:8	III	5	*c*
4957.480.....	1:8	III	5	*c*
4957.785.....	1:8	III	5	*c*
5233.122.....	1:6	III	5	*d*
5324.373.....	1:6	IV	5	*d*
5586.991.....	1:6	IV	5	*d*
5615.877.....	1:6	IV	5	*d*

In some cases these are based on the curves of the Koch microphotometer, but eye-estimates are sufficiently accurate for classification, which is the main object of these tables. The third column gives the class in which the line is placed in the electric-furnace study[1] made by the writer. Later experience with the furnace spectra has slightly modified the method of classification, and the numbers given in parentheses for a few lines denote the class in which the line would probably fall if the classification were revised. The fourth and fifth columns contain the class and the group in which the line is placed by Gale and Adams[2] according to its appearance under pressure and to its pressure displacement, respectively.

The material presented in Tables I and II shows the following relations between the amount of dissymmetry imparted by the

[1] *Mt. Wilson Contr.*, No. 66; *Astrophysical Journal*, **37**, 239, 1913.

[2] *Mt. Wilson Contr.*, No. 58; *Astrophysical Journal*, **35**, 10, 1912.

tube-arc and the behavior of the lines in the furnace and under pressure:

1. Lines of small and moderate dissymmetry of reversal belong in the furnace Classes I and II, those most nearly symmetrical being as a rule among the "flame" lines of Class I. These are all lines occurring at low temperature, the rate of increase in strength with rise of temperature being more rapid for the lines of Class II.

2. Lines which are strongly unsymmetrical in their reversal in the tube-arc are with few exceptions in Classes III and IV. These require a higher temperature for their initial appearance and increase rapidly in strength as the temperature rises.

3. The connection with the behavior of the lines under pressure is very definite. With two exceptions, all lines in Table I are given as symmetrical in appearance under pressure (Classes 1, 3, and 4), and have small or moderate displacements (Groups *a* and *b*). Those in Table II are made unsymmetrical by pressure (Classes 2 and 5), and show large displacements (Groups *c* and *d*).

Lines displaced toward the violet in the tube-arc.—In the green-yellow an important group of lines is found, the strongest of which are λλ 5365.069, 5367.669, 5370.166, 5383.578, 5404.357, 5411.124, 5415.416, 5424.290. The tube-arc gives these lines very strong, diffuse, and nearly symmetrical, a slight shading appearing on the violet side. By measurements to be described later in the paper, these lines were found to give decided displacements toward the violet. In the furnace these lines are to a certain extent in a class by themselves, since no other lines as strong in the iron arc are so difficult to obtain in the furnace. They appear very faintly at high temperature and are an extreme type of Class V lines.

No reversed iron lines with the violet side strongest have been found, but two important cases of this dissymmetry occur in the H and K lines of calcium, which are found on several tube-arc plates of the iron spectrum. In the former paper[1] on the tube-arc, these lines were mentioned as symmetrical, but the greater power available in the later experiments gives them in every case with the violet side stronger, about in the ratio 6:5. The available pressure

[1] *Mt. Wilson Contr.*, No. 73; *Astrophysical Journal*, **38**, 315, 1913.

measurements for H and K indicate that they are displaced toward the red by pressure, so that they appear to present an exception to the general correspondence between the two effects.

Relation to pole-and-center differences in the iron arc.—When a plane-grating spectrograph is used for the observation of the ordinary arc spectrum, the image of the arc from pole to pole being projected on the slit, some lines of iron are found to remain nearly symmetrical from center to pole of the arc and others to become decidedly unsymmetrical near the pole. These differences are being studied in detail by St. John and Babcock. Without giving an extended comparison, it may be stated here that the dissymmetries shown by the tube-arc lines are of the same nature as for corresponding lines in the ordinary arc, but are greatly magnified in amount. This is true also for the lines considered in the last paragraph, which widen toward the violet near the pole of the arc. A comparison by Royds[1] of the pole and center of the arc gave considerable displacements toward the violet for these lines. Another group of lines in this region, found by Royds to give negligible displacements, is included among the tube-arc lines in Table I, while still others showing polar displacements toward the red are in Table II.

Micrometer measurements on unsymmetrical lines.—The group of strong green lines near λ 4900 affords an interesting example of the sort of wave-length measurements that are given by lines of this kind, and also of the relation of the measured displacement to the intensity of the line in question. These lines are in the same furnace class, also in the same pressure class and group. In the tube-arc they are all very unsymmetrical, the violet side of the reversal usually being so faint as to show merely as a shading off on that side, but in the case of two of the group, λλ 4891.683 and 4920.685, the strength of the lines was sufficient to show both sides of the reversal distinctly, so that the measuring microscope could be set on the reversal itself. For the other lines, the maximum was well enough defined to give closely concordant sets of measurements, but these settings were in reality chiefly on the red side of the partially reversed line. An arc spectrum on the same plate given

[1] *Kodaikanal Observatory Bulletin*, No. 40, 1914.

by the center of a 6-ampere arc was measured for comparison. The reference line in each case was λ 4891.683, this being clearly reversed in the tube-arc spectrum. These measurements are given in Table III. The small negative displacement of λ 4920.685

TABLE III

λ	Intensity	Displacement Tube-Arc − Arc
4859.928	8	−0.041
4871.512	25	+0.076
4872.332	12	+0.062
4878.407	5	+0.035
4890.948	15	+0.071
4891.683 (reversal)	30	0.000
4903.502	3	+0.028
4919.174	12	+0.074
4920.685 (reversal)	35	−0.004

is within the error of measurement for lines of this quality. The measured displacements of the others show a rough but distinct relation to the strength of the line. The effect clearly increases with the absolute width of the line, while the example shows the extent to which measured wave-lengths of such sensitive lines may be disturbed in the spectrum of a source of this kind.

Use of the registering micro-photometer.—This brings us to the generally recognized difficulty of making micrometer settings on unsymmetrical lines. One must either set on the reversal, if there is such, in which case no account is taken of the dissymmetry of the sides, or on the position of maximum density, which may well be only one side of a partially reversed line. The Koch microphotometer is of much assistance in this respect. Its use in registering the density-curves for various types of emission lines was illustrated in a previous paper.[1] The large apparatus recently constructed here serves to register the structure of individual lines and also to measure the wave-length interval between lines. If one or both of the lines are unsymmetrical, the position of the ordinate which best represents the maximum of each line must be decided upon. For most of the reversed tube-arc lines, the dissymmetry is chiefly at the top of the curve. Examples are shown in

[1] *Mt. Wilson Contr.*, No. 77; *Astrophysical Journal*, **39**, 213, 1914.

Fig. 1 of two iron lines in different stages of reversal. The wave-length of the corresponding arc line is given closely by the minimum of the reversal, while the maximum of the unsymmetrical line is obtained by producing the slopes of the curves as shown, the ordinate of this maximum being, to a close approximation, midway between the two sides of the curve. If the curve as a whole is very one-sided, owing to shading of the spectrum line, it is more difficult to determine the ordinate for use in a wave-length measurement.

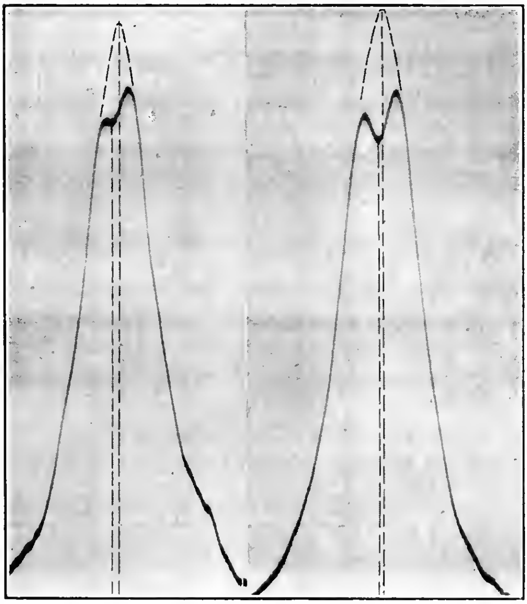


Fig. 1.—Curves of reversed iron lines showing different degrees of dissymmetry in the tube-arc.

Following the plan just outlined, an attempt has been made to measure the displacing action of the tube-arc by obtaining the distance between the centers of pairs of density-curves, one curve being for one of the highly unsymmetrical lines given in Table II, the other for a line, usually from Table I, which could be considered as giving an ordinate practically undisplaced, this ordinate being either that of the reversal of the slightly unsymmetrical line or of its maximum if narrow and unreversed. The curves were registered on direct and reversed runs of the screw to eliminate possible

errors due to inertia in the instrument, which proved, however, to be extremely small. Curves were similarly made for arc lines on the same plate, the portion of the line given by the center of the arc being registered.

A further purpose in measuring these lines was to observe the effect of large differences in the quantity of iron vapor present in the tube-arc. An inspection of photographs made for large and small vapor densities showed the magnitude of the dissymmetry to vary greatly with the strength of the line. With a very small quantity of iron vapor, strong lines such as λ 4383.720 are reversed with the usual degree of dissymmetry; while lines less intense, including many of those which are very unsymmetrical with much vapor present, appear fairly sharp. The question is, Are these weaker lines moved out of their position by the tube-arc to the same degree that they are when strong, or is the effect dependent on the strength of the line? Evidently only a comparison of the distances between the density-curves can decide this question.

TABLE IV

VARIATION IN WAVE-LENGTH OF TUBE-ARC LINES WITH VAPOR-DENSITY

Unsymmetrical Line	Standard Line	Displacement, Tube-Arc – Arc	
		Low Vapor Density	High Vapor Density
4187.204	4185.058	+0.009	+0.019
4187.943	4185.058	+0.009	+0.015
4250.287	4250.945	−0.002	+0.029
4260.640	4271.934	+0.013	+0.040
4271.325	4271.934	+0.008	+0.035
4299.410	4294.301	+0.001	+0.036

Displacements toward the red.—The values in Table IV give the displacement of the center of density of the unsymmetrical line with reference to a neighboring line taken as standard. Thus a positive displacement indicates that the given line is toward the red with respect to its position in the arc measured from the same standard. λ 4185.058, used as standard for the first two lines, is a Class III line in the furnace and, though narrow, probably suffers some displacement in the tube-arc. The curves of the last three lines in the table were the most satisfactory for measurement.

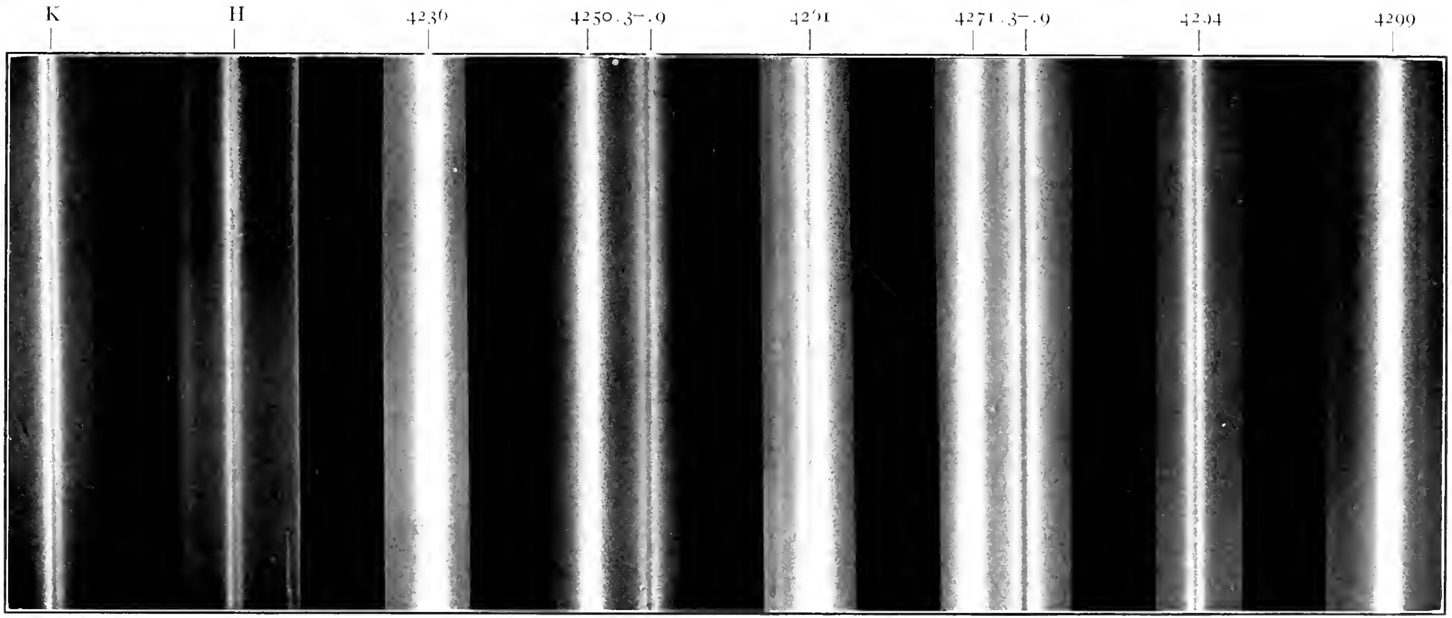
The last column of Table IV gives the magnitude of the displacement measured by the micro-photometer when the tube-arc line shows large dissymmetry; while the third column shows that this displacement becomes small when the width of the line is decreased by low vapor-density. As was previously noted, the tube-arc under the latter condition is still able to produce decided dissymmetry in strong lines such as λλ 4308, 4325, 4384, 4415. How far this effect may be due to differences in vapor-density, strictly speaking, will be discussed later; but evidently the dissymmetry of tube-arc lines does not depend entirely on the strength of the discharge conditions. If it did, the amount of measured displacement to be expected for a line in any source could be calculated from the strength of the enhanced lines in that source; but the effect is complicated by conditions attendant on the amount of vapor present.

The dissymmetries exhibited by some tube-arc lines are shown in Plate VII. First are the calcium lines K and H, which are reversed with the violet side stronger. They appeared thus on several plates which showed the stronger iron lines maintaining their usual dissymmetry toward the red. The iron lines shown are λ 4236.112, highly unsymmetrical, λλ 4250.287 and 4250.945, of large and small dissymmetry respectively, λ 4260.640, showing large dissymmetry, with two satellites on the violet side, λλ 4271.325 and 4271.934, similar to the pair at λ 4250, and λλ 4294.301 and 4299.410, showing a marked contrast in structure.

Plate VII is supplemented by the density-curves in Fig. 2, these being for the same lines as are shown in the plate, with the addition of the iron lines λ 3969.413 (from the same plate as the adjacent H line) and λ 4308.081, made from a plate taken with low vapor-density in the tube-arc.

Displacements toward the violet.—Four of the strong lines in the green-yellow described on p. 377 have been studied with the micro-photometer, the distances being measured in both tube-arc and arc between the curves of these lines and those of standard "flame" lines which reverse almost symmetrically in the tube-arc and may be regarded as probably undisplaced by this source. The arc-curves were made in each case for the part of the line

PLATE VII



UNSYMMETRICAL TUBE-ARC LINES FROM THE SPECTRA OF CALCIUM AND IRON

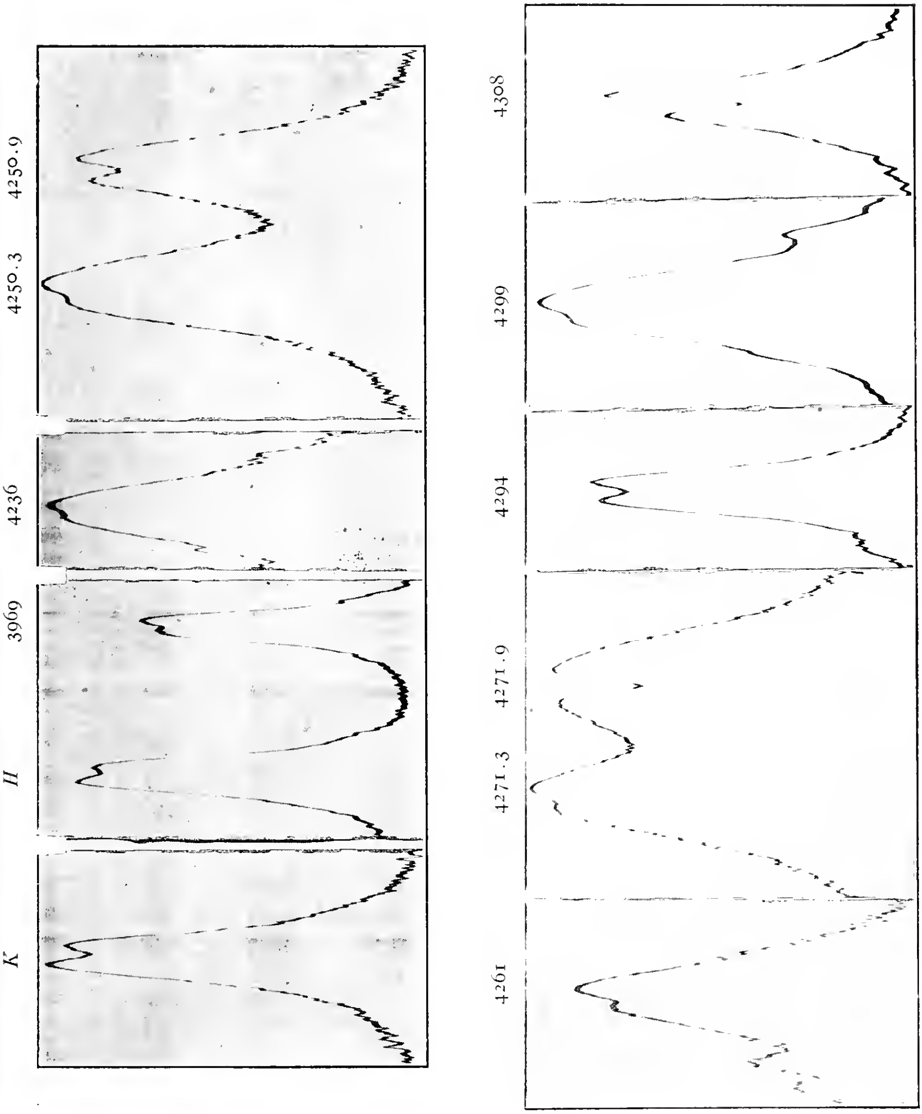


FIG. 2.—Density-curves of tube-arc lines, showing varying degrees of dissymmetry

given by the central region of the arc. The results are given in Table V.

TABLE V

TUBE-ARC LINES DISPLACED TOWARD THE VIOLET

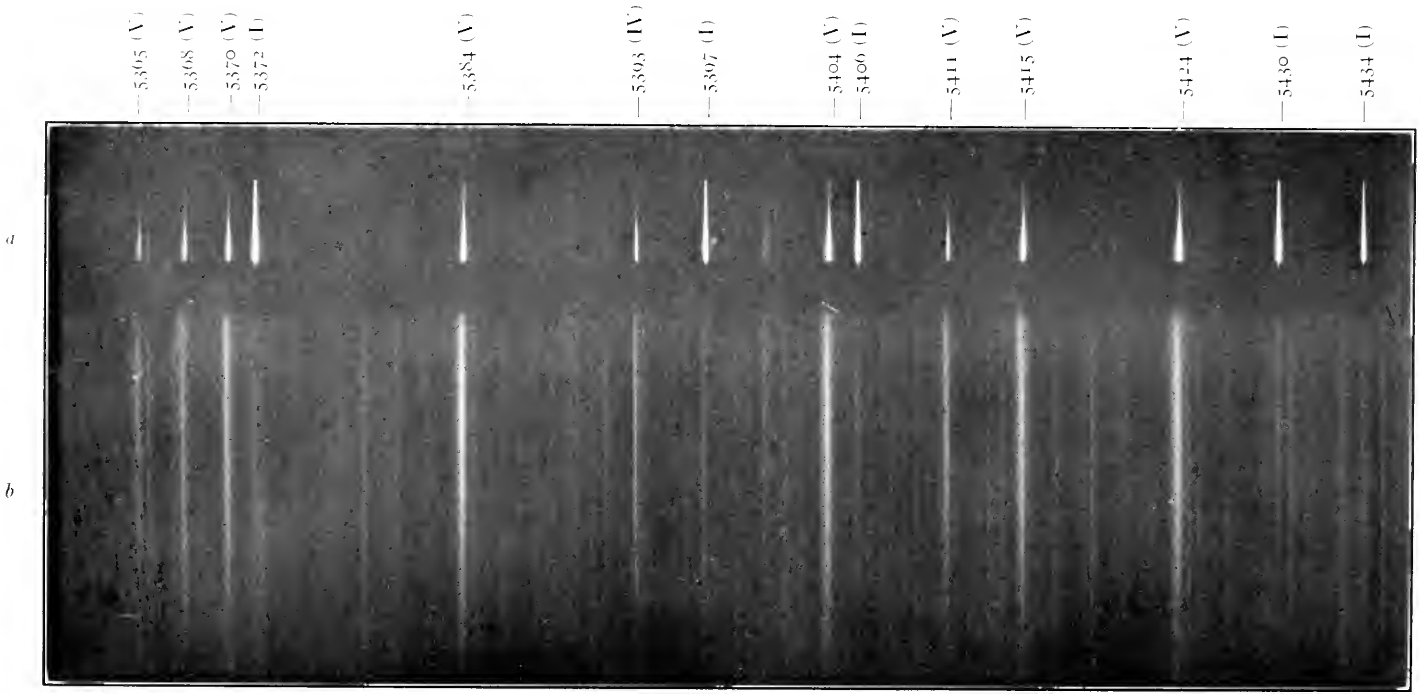
λ (Rowland)	Standard Line	Displacement
5367.669	5371.734	−0.036
5370.166	5371.734	−0.027
5411.124	5405.989	−0.056
5415.416	5405.989	−0.094

These displaced lines are unreversed and the measurements were taken well up on the curve, where it is nearly symmetrical. The bottom of the curve shows a shading toward the violet which would increase the displacement if it were taken into account; but the method employed measures as nearly as possible the position of the strongest part of the line. The displacement of λ 5415.416, the strongest of the group, is seen to be very large, an effect similar to that noted for the lines near λ 4900 (see p. 378), where the measured displacement, in a group of lines showing the same behavior, was found to increase with the strength of the line. The displacements given in Table V are the means of two sets of curves having different scales, made by changing the speed-ratio between the negative and the registering plate. The two sets gave almost identical results, and while no high degree of accuracy can be claimed for the absolute values of the displacements, there can be no question that any method of measurement would give displacements toward the violet of considerable magnitude for the centers of density of these lines.

LINES INTENSIFIED IN THE TUBE-ARC SPECTRUM

It is in harmony with the general resemblance of the tube-arc spectrum to that near the pole of the ordinary arc that the enhanced lines of iron should be brought out strongly and a decided intensification be given to those usually classed as "nebulous" in wave-length tables and thus denoted by the writer in the paper on the furnace spectrum. With few exceptions, they belong in Class V, being absent or extremely faint in the furnace spectrum. In the

PLATE VIII



THE SPECTRUM OF IRON

(a) In ordinary arc, (b) in tube-arc, showing the high intensity of lines in the higher furnace classes (indicated after the wave-length), as compared with the "flame" lines of Class I

ordinary iron arc, these lines are much stronger in the highly luminous part near the negative pole. In the tube-arc, they are very strong, the well-known group in the green-yellow from λ 5365.069 to λ 5424.290 dominating the spectrum in this region. This condition is illustrated by Plate VIII, which shows the tube-arc spectrum with that of the ordinary iron arc for comparison. The strong lines of Class I are scarcely visible, but this is partly due to their being reversed for the greater part of their width, the edges of the reversal being almost symmetrical.

THE TUBE-ARC SPECTRUM IN THE ULTRA-VIOLET AND RED

The investigation of iron in the tube-arc has covered the spectrum from λ 3600 to λ 6600. At the violet end of this range, dissymmetries are numerous, but no features of special interest were observed. The stronger lines reverse with the red side stronger, the dissymmetry being moderate in amount, similar to the lines listed in Table I. The region from λ 5700 to λ 6600 required the first order of a very bright grating, and few deviations from the usual arc spectrum appeared. The stronger lines remained sharp, only a few showing shading toward the red. The diffuse lines were intensified, and the enhanced lines appeared as in other portions of the spectrum.

DISSYMMETRIES IN THE SPARK SPECTRUM

The writer has at intervals during several years photographed the spectrum of the spark under conditions giving a highly disruptive discharge. A powerful transformer spark with large condenser was used, the spark terminals being bluntly pointed rods of iron held in massive brass cylinders for cooling. After the discharge started, a series spark-gap was lengthened until the transformer was just able to maintain an exceedingly noisy spark. Comparison arc spectra were made on each plate by placing an arc in the position formerly occupied by the spark, leaving the lens system undisturbed. Sometimes the position of the spark line with reference to that of the arc was tested by means of the occulting screen, exposures with the arc being made before and after the spark exposure. For a large number of photographs a long slit was used,

on which the image was projected with the axis of the spark at right angles to the slit. The middle of the spectrum line then registered the radiation from the interior of the spark, together with that from the outer vapor in the line of sight; while toward its ends the spectrum line was given by light from the outer vapor alone. Lines sensitive to reversal were frequently reversed almost to the point where the tip faded from the plate. The more striking features observed were as follows:

1. Dissymmetries were found to be very frequent in the spark spectrum and to vary greatly in magnitude for different lines.

2. The relative sensitiveness to dissymmetry among the lines of the spark appears to be quite the same as that observed for corresponding lines in the tube-arc spectrum.

3. In the spark spectrum of iron, two classes of lines, both unreversed in the spark, show no dissymmetry. These are the flame lines (furnace Class I) and the enhanced lines. As will be noted later, exceptions to this rule are found in other spectra when such lines are reversed.

4. The stronger arc lines in the blue and violet, usually of Class II, when photographed with a long slit, show large dissymmetry of the reversal at the middle of the line, the red side being the stronger. Receding from the central position reduces this dissymmetry as the interior vapor of the spark becomes less effective, until at the ends of the long line approximate symmetry is attained.

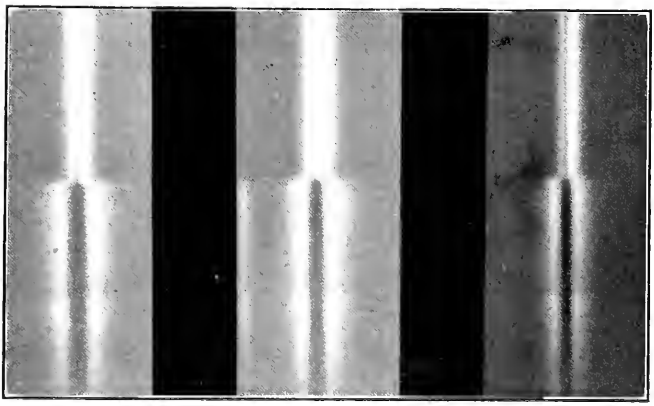
5. When adjacent spectra of the arc and of the core of the spark are made by means of the occulting screen, the position of the reversal is found to coincide closely in the two spectra, thus indicating that the outer vapors of the spark which cause the reversal give a line in the position of the arc line. This conclusion was arrived at by Kent,[1] who compared the lines given by the arc and spark in a concave-grating spectrum.

The features described in Nos. 4 and 5 are illustrated in Plate IX. In the upper section are enlargements of three reversed iron lines, each showing half of the length of the line photographed with the long slit across the spark-image. The unsymmetrical line given by the core is seen to change to a symmetrical line given by the

[1] *Astrophysical Journal*, **22**, 182, 1905.

PLATE IX

a



b

IRON LINES SHOWING DISSYMMETRY IN THE DISRUPTIVE SPARK

a. Half of long line photographed with the slit at right angles to axis of spark.

b. Comparison of spark line (above) with arc line.

outer vapor. In the lower section of the plate, the same lines are shown as photographed by means of the occulting screen, the line given by the core of the spark having below it two exposures of the arc line made before and after the spark exposure respectively. The contrast in symmetry between the arc and spark lines is seen, and also the continuity of the reversal for the two sources.

The effect is further illustrated by the micro-photometer curves of Fig. 3. These show the structure of λ 3737.281 at the middle and near the end of the long spark line and also in the arc. Completing

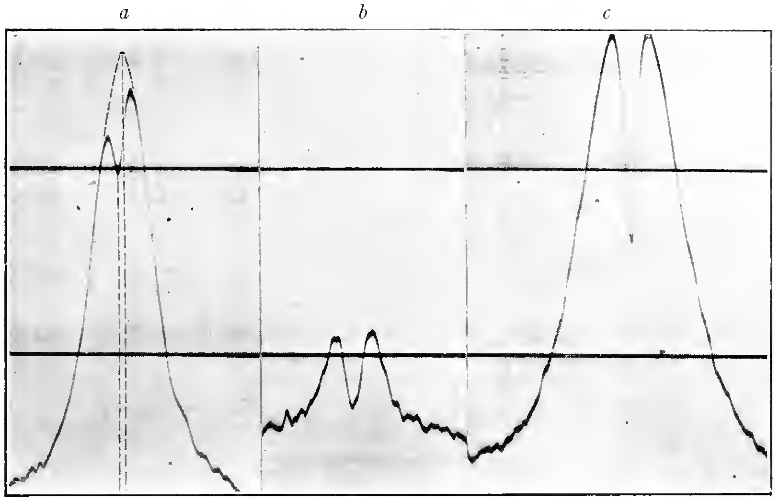


FIG. 3.—Curves of λ 3737 of iron; *a* and *b*, from middle and end of long spark line; *c*, from arc line.

the curve for the unsymmetrical spark line shows the difference between the ordinate given by this and the ordinate of the reversal, which marks the position of the line in the arc.

Both in the appearance of the reversed lines, usually moderately unsymmetrical, and in the density-curves obtained from them, there is a close correspondence between the effects for the tube-arc and the condensed spark in the case of the iron lines listed in Table I. The lines of Table II, which are very unsymmetrically reversed in the tube-arc, do not reverse in the spark on any of my plates, but are winged strongly on the red side. Typical density-curves obtained from lines of this class are shown in Fig. 4.

In contrast with these lines, the strong diffuse lines of the green-yellow, which show dissymmetry toward the violet in the iron arc and are displaced toward the violet in the tube-arc, are shaded strongly on the violet side in the spark. These lines are given relatively strong by the core of the spark and by the most intense regions of the arc.

The evidence indicates that the core of the spark radiates lines which are in general displaced toward the red, probably to different degrees according to the class of the line. Such a displaced line

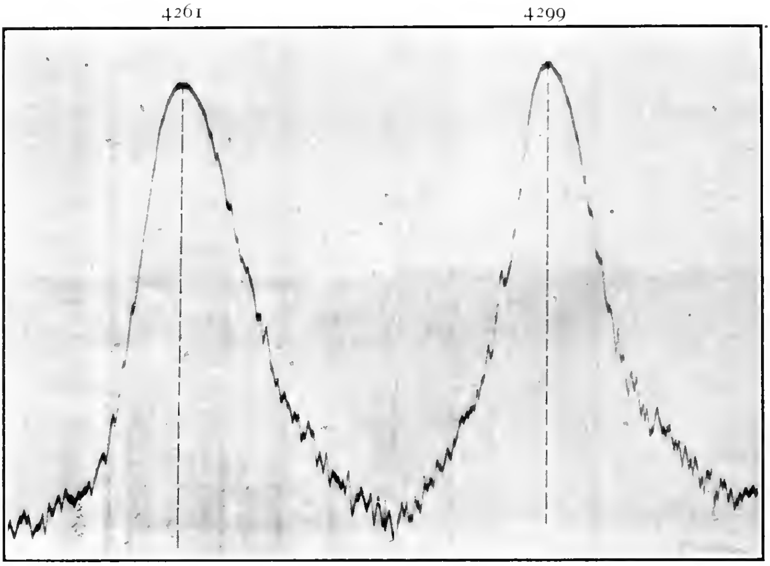


FIG. 4.—Curves of iron lines showing one-sided structure in the disruptive spark

might be symmetrical if a homogenous mass of vapor from the core of the spark could be isolated. The line usually photographed is a composite given by the superposition on this core line of less-displaced radiations from the vapor enveloping the core. The density-curves of the strong reversed iron lines of moderate dissymmetry, usually belonging to furnace Class II, indicate the presence of a symmetrical line from the core of the spark differing in wave-length from the absorption line given by the outer vapor. These lines are quite similar in the tube-arc and spark. The iron

lines at the two extremes of the furnace scale, the flame lines (Class I) and the enhanced lines (Class V E), are very nearly symmetrical in the condensed spark. It is shown, however, with the plane grating and long slit, that the flame lines are given chiefly by the outer vapor and are therefore out of the displacing region while the enhanced lines are confined to the core with no superposed radiation to render them unsymmetrical. The former should, therefore, remain symmetrical and undisplaced, while an enhanced line in the spark should be symmetrical but displaced with reference to the same line in the furnace or center of the arc. Only a few enhanced lines appear in the latter sources, however, and an accurate comparison presents many difficulties on account of the great difference in the strength of these lines in the spark and in the arc or furnace.

TUBE-ARC AND SPARK EFFECTS FOR OTHER ELEMENTS

A study in some detail has been made of the dissymmetries shown by titanium in tube-arc and spark, together with a few photographs of interesting regions in the vanadium and chromium spectra. Alloys of titanium and vanadium with iron were used to secure the highly disruptive spark. The main features observed may be briefly given.

Titanium shows a very close correspondence between tube-arc and spark in the degree to which various lines are made unsymmetrical. Among the strong reversed lines in the blue, certain groups show a decided difference in dissymmetry, this difference being alike in the two sources. λ 4298.89 is an example of symmetrical reversal, while λλ 4527.47 and 4457.61 have their sides unsymmetrical about in the degree 1:2 and 1:4 respectively. Lines of similar structure show a tendency to group in the neighborhood of these lines. While these are for the most part in furnace Class II, the more unsymmetrical lines approach the behavior of Class III lines in the furnace. The strong lines in the green near λ 5000 were examined in the condensed spark and show distinct differences in structure. λλ 4981.93 and 4991.24 show 1:2 dissymmetry while λλ 5036.08 and 5036.65 are more one-sided, about 1:4. Two

Class I lines in this region, λλ 5040.14 and 5064.79, partially reversed in the spark, are nearly symmetrical.

The enhanced titanium lines show considerable variation in the condensed spark. Those in the green are unreversed and very symmetrical in structure. Fig. 5 gives the density-curves for one of these and for a typical titanium arc line in this region. The enhanced lines from λ 3600 to λ 4600, however, are so strong in the spark that many of them are reversed, and these reversals, while usually unsymmetrical toward the red, are unsymmetrical

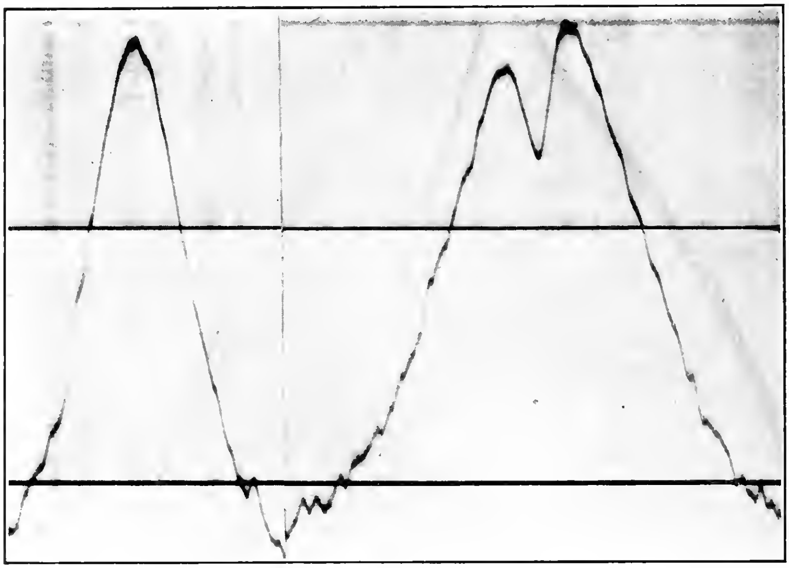


FIG. 5.—Curves of titanium iines in the disruptive spark

toward the violet for λλ 4395.19 and 4444.00. Enhanced lines showing symmetrical reversal are λλ 3685.37, 3759.46, and 3761.47.

The spark spectra of vanadium and chromium were photographed for parts of the violet, blue, and green where distinctive strong lines occur. The plates show dissymmetries of varying amounts to occur very generally, but no decided difference has been noted from the condition prevailing in the iron and titanium spectra. Class I lines of vanadium and chromium show rather larger dissymmetries than those of this class in the other spectra, but these are

very strong lines and the distribution of vapor between the core of the spark and the reversing envelope may be slightly different from that of iron and titanium lines in the same class.

COMPARISON WITH THE PRESSURE-EFFECT

It has been shown that the degree of dissymmetry exhibited by various classes of lines in the tube-arc and condensed spark corresponds closely with their susceptibility to pressure displacement. The question arises whether pressure may be active in the tube-arc and in the spark. Two lines of evidence are against this. First, the dissymmetries show no tendency to become larger with increasing wave-length, as do the pressure displacements, and, second, the tube-arc is operated in a partial vacuum, its action becoming more favorable to strong dissymmetries as the pressure is decreased. In addition to the difficulty of considering a high pressure in the ordinary sense as present in the spark in air, the resemblance of the spark effects to those of the tube-arc is so close that their causes would seem to be very similar. It will be shown later how the action of pressure may be different from that producing the tube-arc and spark displacements and yet produces equivalent effects.

THE INFLUENCE OF VAPOR-DENSITY

Examination of the tube-arc photographs and measurement of such lines as permit of it show clearly that, with the given electrical conditions, the dissymmetry of lines becomes much greater when their width is increased by the use of a large quantity of vapor. The measured displacement becomes small if the line is narrowed by the presence of only a small amount of vapor. However, the spectra given by the regular furnace offer evidence that high vapor-density alone will not render lines unsymmetrical. The writer has never yet observed a line in the furnace spectrum which was clearly unsymmetrical. To be sure, many of the lines most sensitive to this effect are in Class III or Class IV and are therefore narrow and unreversed in the furnace, but a number of strong titanium lines, very unsymmetrical in the tube-arc and spark, are reversed in the furnace at high temperature and remain quite symmetrical. The vapor-density in the furnace must be considerable,

in spite of the large volume of the tube. This is attested by the width of the stronger lines and by the fact that, during the short run required for an exposure, two grams or more of iron may be vaporized so that the tube is afterward found incrusted with it from end to end. In the arc also, lines may be very wide when much vapor is present, and still remain symmetrical. When the poles of the arc are approached, however, the occurrence of enhanced lines indicates a condition resembling the spark, and in this region the lines most sensitive to displacement become one-sided. These dissymmetries are greatly magnified in the tube-arc and in the disruptive spark.

A considerable degree of harmony among these effects is obtained if it is permissible to consider as a necessary condition the presence of electrified particles moving at high velocities. These are supplied in the spark and at the poles of the arc by the high potential gradients. The cause for the very similar spectrum effects in the tube-arc, where the potential is low, is not so clear, and at present the writer can only refer to the suggestion offered in a previous paper[1] that the heated carbon ejects electrons which are given high velocities by the explosive conditions at the point of rupture. We know that at this point there is a great concentration of electrical energy, and the effects would seem to indicate that the action of the tube-arc produces a superheating of the carbon in virtue of which the electrons are given velocities comparable with those imparted in other sources by a high potential. If this possibility is admitted, the effect of high electronic speeds in causing a disturbance of period should be increased by the crowding together due to high vapor-density, and on this account the relation to the pressure effect may be a close one. Spectrum lines from the furnace or from the center of the arc, given by particles having low velocity, are displaced by the crowding due to pressure. If the source does not have high pressure, but is such that the particles have high velocities, the tendency of these velocities to disturb the period would be expected to increase with the density of the vapor.

A consequence of this point of view would be that high pressure should give large displacements for lines which are strengthened

[1] *Mt. Wilson Contr.*, No. 73; *Astrophysical Journal*, **38**, 315, 1913.

by strong electrical conditions. This is borne out by the large pressure displacements found for lines in Classes III and IV of the furnace classification. These lines are much stronger in the arc and spark than in the furnace. Further, Gale and Adams[1] observed that the enhanced lines as a class are displaced by pressure more than the arc lines, and that for a given pressure the enhanced lines are displaced more in the spark than in the arc. They note also that when the arc and spark were observed at the same pressure, the lines in general show "a marked tendency toward higher values for the spark displacements." All of these effects would follow as a direct result of a combination of high electrical action with high pressure.

Royds,[2] in reviewing the displacement effects observed as a result of arc dissymmetries, arrives at the conclusion that vapor-density plays an important part, while recognizing the possible influence of ionization in the arc and spark, and suggests "density of ions" as a substitute for "vapor-density" as the displacing cause. I believe this idea is in the right direction and would make a further modification by suggesting *density of high-speed electrons* as a condition which appears to harmonize the results for the displacements of the arc, spark, and tube-arc with those for the pressure-effect and to account for the evident connection of all of these with the furnace classification.

SUMMARY

1. The results for the tube-arc and the disruptive spark show that these sources impart an unsymmetrical structure to many of the stronger spectrum lines, the micro-photometer indicating that this is caused by the region of strongest excitation giving a displaced line, usually to the red.

2. Much variability appears in the amount of this dissymmetry for different lines, its magnitude clearly being related to the furnace classification of the lines and to their displacement under pressure.

3. Iron lines of small and moderate dissymmetry in the tube-arc are low-temperature lines and show only moderate pressure-effect.

[1] *Mt. Wilson Contr.*, No. 58; *Astrophysical Journal*, **35**, 10, 1912.

[2] *Kodaikanal Observatory Bulletin*, No. 40, 1914.

4. Lines of large dissymmetry are faint in the furnace relatively to the arc and are greatly displaced by pressure.

5. The degree of dissymmetry in the tube-arc, for each of the foregoing classes, has a distinct relation to the width of the line, so that, other things being equal, strong lines are more displaced by this effect than faint ones and an increase of vapor-density increases the dissymmetry.

6. The most symmetrical lines of iron in the tube-arc are the "flame" lines. The H and K lines of calcium reverse with the violet side strongest.

7. Lines unsymmetrical toward the violet in the spark and near the pole of the arc are displaced toward the violet in the tube-arc.

8. The nebulous lines of iron, requiring strong arc conditions, are much intensified in the tube-arc.

9. A powerful and disruptive spark produces line dissymmetries which in general are very similar to those of the tube-arc. The most symmetrical iron lines in this spark are the "flame" lines and the enhanced lines.

10. Analysis by the plane grating shows the radiation from the core of the spark to be displaced toward the red, in the case of most of the stronger lines, the outer vapor giving a symmetrical line in the position of the arc line.

11. The results indicate that a condition of strong electrical excitation, combined with high vapor-density, produces a condition the displacing action of which shows many resemblances to the effect of pressure.

The writer wishes to acknowledge the valuable assistance of Mr. Colby and of Mr. Monk, who operated the micro-photometer in registering the curves for this investigation.

Mount Wilson Solar Observatory
April 20, 1915

AN APPARENT RELATION BETWEEN THE RADIAL VELOCITIES OF THE STARS AND THEIR MAGNITUDES

By. C. D. PERRINE

In a former paper[1] I presented evidence showing a relation between the inherent radial velocities of 225 of the brighter stars of Class B and their magnitudes, the fainter stars having the greater velocities.

The investigation has now been extended to cover the stars of Classes A, F, G, K, and M as contained in Campbell's lists published in *Lick Observatory Bulletin*, Nos. 211 and 229.

The results given below are derived from Campbell's V_2 value for the stars of Class A and similar values of the radial velocities of the other classes. For classes F, G, K, and M these values were obtained by correcting the observed velocities for the solar motion, using $\alpha=270°$, $\delta=+30°$, $V_{\odot}=-19.5$ km, and $K=0$.

In order to make the entire investigation more homogeneous new results were obtained for the stars of Class B also, using the same apex and value of V as for the other classes and ignoring K. The results are included in the following tables along with the others. These differ somewhat in detail from those published earlier, which include the effect of the K term. The dependence upon magnitude is still shown, however, although not with so large a range.

It is perhaps a question as to the best system for such an investigation—whether the exclusion of the K term represents the real velocities of the stars more accurately or not. I have found some very peculiar results of a semi-systematic nature in practically all of the classes, for groups in different parts of the sky, which make me doubt the advisability of assuming that K depends simply on spectral class or subdivision. I hope to publish the preliminary results of that investigation soon. In the meantime I prefer to treat the present investigation without any limitation in that respect.

[1] *Astrophysical Journal*, 41, 315, 1915.

The means of the velocities by classes and magnitudes are given in Table I.

TABLE I

	B		A		F		G		K		M	
	No.	*V*	No.	*V*	No.	*V*	No.	*V*	No.	*V*	No.	*V*
1.9 and brighter	11	5.7	8	15.1	11	11.5	7	12.5	6 5*	14.8 9.2	16	12.5
2.0–2.9..	19 *17	8.0 6.2	19	12.2					25	12.1	*14.	8.6
3.0–3.9..	43	7.3	26	8.7	28	16.3	23	13.7	87	15.3		
4.0–4.9..	152	7.9	121	10.7	161	14.9	108	13.7	309	15.9	64	18.5
5.0 and fainter.			38	12.6		.....	....	.....	....	.....	....	.....

* Rejecting one or two abnormally large velocities.

To test any possible effect of the known preference of the higher velocities for the Milky Way, the results were classified also in that respect. The result is shown in Table II.

TABLE II

Class	Magnitude	0° to ±20°		±20° to ±40°		±40° to ±90°	
		No.	Mean *V*	No.	Mean *V*	No.	Mean *V*
			km		km		km
B.........	2.9 and brighter ..	24	7.5	1	4.9	5	6.1
	3.0 and fainter....	132	8.1	33	8.4	26	4.1
Ap........	2.9 and brighter ..	2	22.1	0	......	3	4.3
	3.0 and fainter....	1	14.8	4	7.4	5	5.3
A.........	2.9 and brighter...	7	16.1	2	7.0	3	8.3
	3.0 and fainter....	21	10.8	16	10.2	34	9.3
A1–A3...	2.9 and brighter...	3	22.9	1	0.6	3	8.9
	3.0 and fainter....	21	12.2	12	13.8	27	8.8
A5–A8...	2.9 and brighter...	2	14.6	0	......	1	4.9
	3.0 and fainter....	16	13.2	5	8.7	23	13.1
F.........	2.9 and brighter...	8	13.6	2	7.3	1	2.8
	3.0 and fainter....	65	15.9	35	17.8	84	13.4
G.........	2.9 and brighter...	3	17.9	0	......	4	8.5
	3.0 and fainter....	46	26.5	32	29.2	60	16.0
K.........	2.9 and brighter...	15	11.7	9	10.9	8	23.2
						6	13.0*
	3.0 and fainter....	156	17.8	103	19.4	152	16.5
M.........	2.9 and brighter...	3	9.4	2	9.5	2	18.6†
	3.0 and fainter....	16	19.5	17	17.4	35	15.4

* Rejecting two large values of 68.7 km and 38.4 km.

† The individual values are 35.7 km and 1.5 km.

Finally the results were generalized by combining all results into two classes of magnitude, viz., 2.9 and brighter, and those of 3.0 and fainter. The results are given in Table III.

TABLE III

Class	2.9 and Brighter	3.0 and Fainter
	km	km
B.	6.6	7.6
A.	12.5	10.8
F.	11.5	15.6
G.	12.5	13.7
K.	12.0	15.6
M.	10.6	18.5
All.	11.0	13.6

As a further test of the reality of this dependence upon magnitude, the velocities of the B stars in the region of sky from 10^h to 14^h were tabulated. As these stars are practically all in the Milky Way and the center of this region at 90° from the apex, the result should be almost entirely free from systematic errors depending upon uncertainties in the velocity and direction of motion of the observer and from the effect of large or small systematic velocities in different regions of the sky, should the distribution not be essentially uniform. The result is given in Table IV.

TABLE IV

	No. of Stars	*V*
		km
1.9 and brighter. . .	5	5.3
2.6–3.3.	6	6.7
4.0 and fainter.	20	10.1

The increase of velocity with decrease of brightness is clearly exhibited in all classes except A, where the reverse seems to be true. The stars for that class were arranged, not only with respect to the galaxy, but also with respect to the spectral subdivisions. This classification showed that the apparent exception was only in the stars of the galaxy—all of the A stars in other parts of the sky conforming to the condition observed in the other classes, notwithstanding the small number in each compartment.

In the galaxy, however, all the subdivisions show a decidedly higher velocity for the brighter stars than for the fainter ones. This can hardly be mere coincidence even in such meager data, and probably indicates a real tendency and not simply an accidental accumulation of high velocities, although it is to be noted that in the stars of Classes F, G, and K, where large velocities as well as quite small ones are frequent, it is not difficult for accidental accumulation in small groups to form apparent exceptions. Such a case probably is that of the stars of magnitude 3.0–3.9 in Class F.

It is to be observed that the bright galactic A stars show velocities much higher than the brighter stars of the other classes, whereas the fainter galactic A stars fall in the progression according to class.

A possible explanation of this apparent abnormality is that these stars have acquired high velocities under some exceptional condition, for they are considerably higher than the average fainter stars of the same class. Another explanation which satisfies the condition, provided the increase of velocity with decrease of brightness extends also to fainter magnitudes than those at present observed, is that some such stars have wandered sufficiently near to appear relatively bright.

CONCLUSIONS

The foregoing investigation strongly indicates a dependence of the inherent radial velocities of the brighter stars of Classes B, A, F, G, K, and M upon magnitude.

The stars involved number 1309, over half of the total number of stars of magnitude 5.5 and brighter, and therefore give confidence of representing the real conditions existing among such stars.

Strong corroboration of this conclusion is found in the fact that the highest velocities are found only among the fainter stars, not a single instance to the contrary being known.

Of the 38 stars in the list having velocities of 50 km and over, only one is as bright as magnitude 2.4 and four are between 3.0 and 4.0. There are five stars of 100 km and over, the brightest of which is of magnitude 5.2—the mean magnitude of the five being 6.9.

As the stars of greatest known velocities are below the visible magnitudes, it seems reasonable to suppose that an increase of velocity may also continue with decrease of magnitude below the fainter limit of this investigation.

The magnitude-velocity equation appears to increase in the stars of later type.

Campbell concluded[1] from his investigations that the radial velocities increase toward the galactic plane, especially among the stars of earlier class. My own investigations tend to confirm that conclusion. The greatest velocities among the fainter stars of Classes F, G, and K appear to be on the edges of the Milky Way rather than near its central line.

The highest velocities known show a decided preference for the Milky Way. Seventy-five per cent of the velocities of 50 km and over are within 40° of the galactic plane and 40 per cent are within 20°. All five stars having velocities over 100 km are within 40° of the galactic plane.

The cause of such a dependence upon magnitude may be complicated or obscure, but at first sight it seems most likely to result from one of two causes, viz.: (*a*) a difference in size or density, or both, in conjunction with some form of resisting medium; (*b*) that the fainter stars are those which are farther away from the observer and nearer to a source of general gravitational action. That the Milky Way is deeply concerned in either case seems probable.

Here again, as in almost all other problems relating to the arrangement of the universe of stars, we need more complete knowledge of their distances and masses. An investigation of these conditions should aid materially in explaining the cause of this dependence upon brightness.

Observatorio Nacional Argentino
Córdoba
March 17, 1915

[1] *Lick Observatory Bulletin*, No. 196, p. 130.

Minor Contributions and Notes

A SENSITIVE PHOTO-ELECTRIC CELL

Many investigations require a sensitive photo-electric cell equipped with a quartz, or fluorite, window. The most sensitive cells are those in which the photo-electric metal is a layer of sodium, or potassium, prepared by distilling *in vacuo*. Descriptions of methods of preparation of this type of cell have been given by Hughes[1] and by Ives,[2] but it is believed the following method is more simple and easier to carry out.

A glass bulb 4 cm in diameter is blown, with three side-tubes *A*, *B*, and *C* (Fig. 1). A brass wire is sealed in *B*, and from *B*

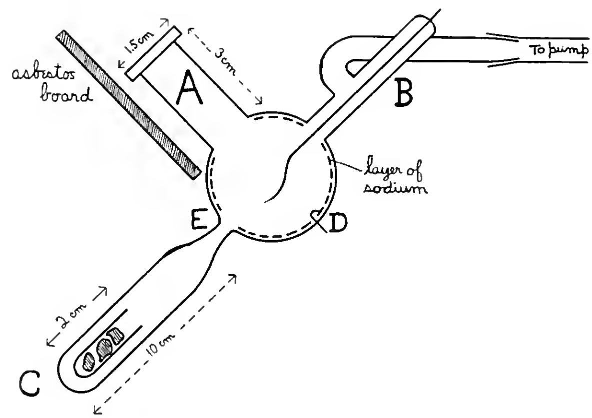


FIG. 1

a side-tube leads to the pump through a ground-glass joint, so that the whole cell may be rotated. On *A* is sealed the quartz (or fluorite) window with red sealing-wax. *D* is a platinum electrode, bent over until it touches the interior of the glass surface, to insure contact with the layer of sodium. The cell is thoroughly cleaned with chromic acid and alcohol, and dried. A small glass capsule is

[1] *Phil. Mag.*, **25**, 679, 1913.

[2] *Astrophysical Journal*, **39**, 428, 1914.

stuffed full of clean metallic sodium (of course covered with the oxide) and this capsule is then placed in the tube C, which is thereupon sealed off. The cell is then connected to the pumps by means of the ground-glass joint and is exhausted. With the tube A vertically upside down, so that the quartz window may be immersed in water, the whole cell is heated all over with the flame of a small blast-lamp as hot as advisable (too hot to touch). The pumps are running all the while to take away any gases which may be driven from the glass surface, and the cell is then allowed to cool. When cool it is rotated into the position shown in Fig. 1. The quartz window is protected now by an asbestos shield and is kept cool by a wad of wet cotton. By a careful manipulation of the small blast-lamp the sodium is distilled up through the constriction E (which must be of even thickness, and well annealed), and soon the whole interior of the bulb is covered with a layer of sodium. A glance into the cell shows that the interior is covered with a beautiful deposit in the form of white droplets. When the layer is fairly opaque to transmitted light enough sodium has passed over, and the distillation is stopped.

During the distillation E must be kept very hot, but care must be taken that no sodium vapor condenses on the quartz window. The pumps must be running during the entire process, for the sodium gives off hydrogen in large quantities. The constriction E must finally be heated enough to clean the glass entirely of any sodium, and then the tube C may be sealed off. Unless E is clean, the seal will surely crack upon cooling. Finally the cell is sealed off from the pumps. This method yields an extremely sensitive cell.

E. O. Hulburt

Johns Hopkins University
May 7, 1915

THE SPECTRAL DISTRIBUTION OF THE STARS OF LARGE RADIAL VELOCITY

In classifying the stars for various purposes, it was noticed that the largest radial velocities appeared to be in Classes F, G, and K. It became of interest and of importance in properly interpreting

certain relationships to examine the distribution of these very high velocities. Table I exhibits the principal results of that investigation.

TABLE I*

	B	A	F	G	K	M
Total stars	225	212	200	153	443	80
No. of stars, 50 km and over	0	0	3	16	16	4
No. of stars, 50 km and over per 100	0	0	1.5	10.5	3.6	5.0
Mean velocity	....	....	99.6km	91.5km	71.4km	55.6km
Mean magnitude	....	....	6.1	5.4	4.3	4.4
No. of stars, 100 km and over	0	0	1	3	1	0
Mean velocity,† all stars in class	7.7km	11.0km	14.9km	21.4km	17.5km	17.3km

* Compiled from Campbell's catalogues.

† Corrected for solar motion of −19.5 km and $K = 0$.

tion. This tabulation shows that the largest number of great velocities, the greatest velocities, and the highest average for the large velocities occur in stars of Classes F and G.

This result from 1300 stars almost certainly represents correctly the general tendency in the naked-eye stars and probably in the stars to eighth or ninth magnitude as well.

Table II shows the result of additional velocities determined at Mount Wilson from stars having large proper motions and published in the *Mt. Wilson Contr.*, Nos. 59 and 79. Only those stars having velocities of 50 km and over are included. These results

TABLE II

	B	A	F	G	K	M
No. of stars	0	2	4	6	3	1
Mean magnitude	....	7.6	7.2	6.4	6.5	7.6
Mean velocity	....	154 km	178 km	64 km	54 km	85 km

tend to confirm the conclusion already arrived at, but to place the highest velocities rather earlier in the spectral scale. It is not, of course, contended that the numerical results are more than approximate. All recent investigators have shown that the stars of Classes

F and G have the largest average proper motions and are the nearest to us. The conclusion from this is that the average stars of Classes F and G, solely because of their nearness, appear brighter to us than the average stars of any other class of the same size or absolute brilliancy.

The finding of the maximum of radial velocities among the faint stars of Classes F and G tends still further to confirm the conclusion that the radial velocities, and probably the total velocities, are functions in general of the brightness of the stars and possibly also of their sizes or masses.

C. D. Perrine

Observatorio Nacional Argentino
Córdoba
April 7, 1915

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